

MAGNETISM, ELECTRICITY AND ELECTROMAGNETISM UP TO THE TIME OF THE CROWNING WORK OF MICHAEL FARADAY IN 1831: A RETROSPECT.

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"Every student of Science should be an antiquary in his subject"—CLERK MAXWELL

"Justice exacts that those by whom we are most benefited should be most honoured."—SAMUEL JOHNSON ("Rambler")

PREFACE.

The approaching centenary of Michael Faraday will be concerned chiefly with his long course of experimental researches in magnetism and electricity, culminating in his crowning discoveries of volta-electric induction on the 29th August, 1831, and of magneto-electric induction on the 17th October following.

It occurs to the author that it will be useful to place these results in proper perspective to the discoveries of the past, and especially to the researches by a brilliant band of physicists early in the last century, all of whom were Faraday's contemporaries—many of them his personal friends. This paper was written with this object in view, and it is hoped that it will be helpful in enabling the educated public, who have little time for historical studies, to follow the Centenary proceedings with interest, and with a clear appreciation of the significance of Faraday's work.

Section 1.

MAGNETISM.

EARLY REFERENCES

Of the two sciences or departments of knowledge, magnetism and electricity, with which we are here concerned, magnetism is by far the older, stretching back to ages before our era. Magnetic oxide of iron is now known to be spread widely over the globe as a natural mineral, but in early times it was found only in Magnesia, Lydia, and the island of Elba. Isolated fragments were observed by Aristotle, Pliny and other ancient writers, to have the power of attracting bits of iron; and, as at that time these fragments were found most frequently in Magnesia, they have come to be called magnetic stones or natural magnets. They are also known as leading-stones or loadstones, from the stony appearance of the ore. A tradition exists in China respecting a mountain of magnetic ore, which rises in the Chinese Sea and which has an attractive power so great as to draw the nails and supporting iron bands from an approaching ship, so that the latter falls to pieces. Ptolemy, who wrote in the first century of our era, repeats this fable in his work on geography.

Coming down to later times, we find the attractive power of the loadstone a matter of frequent observation and experiment. Thus, St. Augustine ("De Civitate

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Dei," circa 413) tells us that, when visiting a friend, he saw him take a magnetic stone and hold it under a silver plate on which was placed a piece of iron, the last-mentioned following all the movements of the hand holding the magnet. He adds that at the time of his writing he had on a table 6 inches thick a vessel filled with water containing a needle attached to a floating cork, which he could move hither and thither according to the movements of a magnet held under the table. Leonardus Camillus in his "Speculum Lapidum," 1502 (*verbo* Magnes), refers to this experiment as one familiar to mariners; and Blasius de Vigenere in his "Annotations of Livy" (Paris, 1576) says that a letter might be indicated through a stone wall 3 feet thick by guiding (by means of a loadstone) on one side of the wall the needle of a compass (on the other side) over the letters of the alphabet, written round the circumference of the card. From such experiments as these the suggestion of a sympathetic needle telegraph, so numerous in the 16th, 17th, and 18th centuries, was but a step, involving only the supposition that the same effect is possible at great distances.

DISCOVERY OF POLARITY AND THE COMPASS.

Besides its attractive power, the polarity of the magnet—that is, its property of taking up a north and south position when freely suspended—was known to the Chinese from an early period. Thus, in the 2nd century B.C. we find allusions to "magnetic cars"† with which ambassadors from distant countries were provided in order not to miss the way on their return home. In the 4th century of our era Chinese navigators employed the magnet to direct their courses across the open seas; and it was through these men that the knowledge of the compass is said to have been carried to India, and thence to the eastern shores of Arabia and Africa. The Arabic designations "Zoron" and "Aphron" (south and north), which Vincent de Beauvais ("Speculum Naturale," Paris, 1473) gives to the ends of the magnetic needle, indicate the source whence Western nations received the rudiments of their scientific knowledge. Owing to the unsteadiness of the first Chinese needles (fixed in cork floating on water) their indications were not always reliable. When, therefore, in the 12th century A.D. they took to suspending the needle in air from a fine cotton or silk thread a great improvement was effected, and with this contrivance they are said to have observed and measured the local declination from the true pole.‡

† Cars on which slender bars or needles of loadstone were mounted as in a compass.

‡ It must be remembered that the Chinese compass differs from the European, in having a mark on the South-seeking pole of the needle and in having the card divided into 24 points, starting from the South pole.

The knowledge of the Chinese compass in Europe is attributed to some people of Amalfi in Sorrento Peninsula, who were skilful mariners and known for their commerce with the Middle and Far East. At all events some specimens of the primitive instrument appeared in Amalfi, and soon improvements were effected by substituting a pivoted needle for the floating one, and adding the graduated card (starting from the North pole), or "Rose of the Winds" as it was called. The name of this benefactor is not known, but as Favio Gioia was then (1302) a distinguished navigator—even in his own country—his name has come to be associated with the importation and improvement of the compass as we know it to-day.*

DECLINATION.

The use of the compass in navigation soon led to the discovery of another property of the magnet—its declination or deviation from the North Pole according to locality. It was known to the Chinese in the 12th century, as it is mentioned by their philosopher Kon Tsung Chy, who wrote about the year 1111; and Columbus made the same discovery on his first voyage to America in September 1492. He noticed that at first his needle, instead of pointing to the North Star, varied half a point to the north-west, and the deviation increased in the following days. After careful observations during his succeeding voyages, he wrote in 1498: "Each time that I sail from Spain to the Indies I find, as soon as I arrive 100 miles west of the Azores, an extraordinary alteration in the motions of the heavenly bodies, in the temperature of the air, and in the character of the ocean; and I also notice that the deviation of the compass needle which before had been north-east now turns to north-west."

Two centuries later, in 1683, Edmund Halley (of comet fame) read a paper before the Royal Society ("Theory of the Variation of the Magnetical Compass"), in which he says: "The deflection of the magnetical needle from the true meridian is of that great concernment in the art of navigation that the neglect thereof does little less than render useless one of the noblest inventions that mankind has ever yet attained to."

The whole globe of the earth is one great magnet, having four magnetical poles or points of attraction. The positions of these poles cannot as yet be exactly determined, from want of sufficient data, but I conjecture that the magnetic pole, which principally governs the variations in Europe, Tartary, and the North Sea, is about 7° from the North Pole of the earth, and in the meridian of the Land's End; while the magnetic pole, which influences the needle in North America, and in the Atlantic and Pacific Oceans from the Azores westward to Japan, is 15° from the North Pole, and in a meridian passing through the middle of California. The variation in the South of Africa, in Arabia, Persia, India, and from the Cape of Good Hope over the Indian Ocean to the middle of the South Pacific, is ruled by the most powerful of all these magnetic poles, which is situated 20° from the South Pole of the earth, and in a meridian passing

through the island of Celebes; in the remainder of the South Pacific Ocean, in South America, and the greater part of the South Atlantic Ocean, it is governed by a magnetic pole 16° from the South Pole in a meridian 20° west of the Straits of Magellan."

In later years, 1698–99, Halley was sent in command of H.M.S. "Paramour" with instructions "to seek by observations the rule of variations of the compass, and to survey and lay down the latitude and longitude of His Majesty's American Settlements." The voyage included the coast of the Brazils and the West Indies on the one side, and the west coast of Africa, Madeira, and the Canaries on the other, and resulted in the publication in 1700 of his magnetic chart, on which are shown the isogonal magnetic curves or "Halleian lines" of equal variation.

INCLINATION OR DIP.

The property of inclination or dip of the magnetic needle was the last to be discovered, the earliest reference to it being by George Hartmann of Nuremberg in 1543. It was better understood and described by Fortunius Affaytatus of Cremona in 1547, and by Martin Cortes in 1551; but it only became known through the labours of Robert Norman, a nautical instrument-maker of Wapping, who began his observations in 1576, and published an account of them in his "Newe Attractive" in 1581.

The dip of the needle has its variations corresponding to those of the declination. In Robert Norman's time it was a little to the east of north, and less than it is now. It went on increasing until about 1825, when its deviation from the true north was at its greatest.

WORK OF WILLIAM GILBERT.

From the foregoing it will be seen that many and important properties of the magnet were known and applied in early times, long before they came to be studied as a science. The first systematic investigation was made by Dr. William Gilbert of Colchester (see Plate 4), who, after many (18) years of study and research, published in 1600 his great work "De Magnete." In that remarkable book the crude speculations of the schoolmen and the "old wives' tales" were brushed aside, and the foundations of magnetic philosophy were laid on the sure ground of experiment.

The work is divided into six books. The first treats of previous accounts of the loadstone, its origin and properties, of iron ores generally, and of the fables which had grown up round the magnet. The second book is on magnetic motions, and chiefly on the attractions and repulsions between loadstones, and between the loadstone and iron. Here occurs a notable digression on the properties of amber and other substances which when rubbed show signs of electrical excitation. After this digression, which will be referred to later, Gilbert returns to the attracting and repelling powers of the loadstone, and to the way they are affected by giving it different shapes. In the course of this inquiry he enunciates his very important discovery of the increased power of the loadstone when armed with iron caps. Here occurs a further pregnant passage in which he imagines that the loadstone is surrounded by a sort of

* The 6th centenary of this event was celebrated in Amalfi in 1902, when a fine statue was erected in his honour as "Inventore della Bussola Moderna," and an excellent paper on the subject appeared in *Nuova Antologia* (November 1902) from the pen of Filippo Porena.

atmosphere, or "Orbe of Virtue," within which the magnetic effects take place. Book III, on the directive property of the magnet, is full of instructive experiments in which his *terrella*, or small loadstone in globular form, figures largely.

All this leads up to his grand conception of terrestrial magnetism. He even marks his *terrellas* with poles, equator, and meridians to correspond to those on the great magnet, the earth. He dilates on the fact that vertical iron rods, such as the finials on churches, acquire spontaneously magnetic properties due to the earth's magnetism, and he imitated this effect by magnetizing iron bars by hammering them on an anvil while they lay in a north and south direction (see Plate 4).^{*} Book IV deals with the declination of the magnetic needle from a north and south position. He discusses its measurement in time and place, the influence of islands, and the results obtained by travellers in widely separated parts of the earth. He then recounts his own experiments with *terrellas* with uneven surfaces to represent the irregularities of the earth's crust. With these he observed the dip of minute needles at various points of the *terrella*, and evolved a theory on the relation which he conceived (erroneously) to exist between latitude and dip, which, if true, would enable seamen to find their position at sea. In Book V he discourses on the Greek doctrine of the animate nature of the universe, and holds that Thales was right in saying that the loadstone is animate, being part of its animate mother, the earth. Book VI relates not so much to magnetism as to the Copernican theory of the world, which Gilbert eagerly espoused and was the first to proclaim in England.

From this brief synopsis it will be seen that Gilbert's claim to our veneration rests, not so much on capital discoveries or inventions, as upon his building-up of a complete magnetic philosophy on the basis of experiment in place of wild speculations. By his splendid generalizations from small models (*terrellas*) to the great globe of the earth itself, he created the science of terrestrial magnetism, and if from the imperfect data at his disposal he fell into some errors on minor points, yet he founded in England the method of philosophizing by which those errors were in due time corrected. For this and for his masterly vindication of the scientific method, and his rescue of magnetism from the pedantry and charlatanry into which it had fallen, his memory must be held in high renown. As Dryden sang—"Gilbert shall live till loadstones cease to draw."[†]

WORK OF GALILEO.

The great Italian astronomer and physicist Galileo Galilei (see Plate 5) was a whole-hearted admirer of the work of Gilbert—"il grandissimo filosofo," as he called him—and the "*De Magnete*" at once attracted him,

^{*} Writing on this subject in 1874, Sir William Thomson (afterwards Lord Kelvin) says, "But how the earth acts as a great magnet—how it is a magnet—whether an electromagnet in virtue of currents revolving under the upper surface, or whether it is a magnet like a mass of steel or loadstone, we do not know. This we do know, that it is a variable magnet, and that a first approximation to the variation consists in a statement of motion round the axis of figure—motion of the magnetic poles round the axis of figure—in a period of from 900 to 1 000 years."

[†] Gilbert died, of cholera it is said, on the 10th December, 1603. The tercentenary of his death was celebrated by the Institution of Electrical Engineers on the 10th December, 1903, on which occasion they presented to the Mayor and Corporation of Colchester the oil painting (by Ackland Hunt) of Gilbert showing his experiments to Queen Elizabeth and her Court (see Plate 4).

firstly, because its argument traversed many dogmas of the Aristotelian school, and secondly, because it contained a number of original experiments in electricity and magnetism, coupled with philosophical reflections of a far-reaching kind which appealed to his own daring spirit. Especially was he taken with Gilbert's conception of the earth as a great magnet. "I extremely praise, admire, and envy this author," he says, "for that a conceit so stupendous should come into his mind, which had been handled by so many sublime wits, and hit upon by none. I think him, moreover, worthy of the highest praise for the many new and true observations which he has made to the discomfiture of so many vain and fabling authors, who write, not from their own knowledge, but retail everything they hear from the foolish vulgar, never seeking to assure themselves of its correctness by experiment."

His own study of the loadstone, begun before 1602, was suggested by the chance perusal of Gilbert's book,^{*} but he did not go very far. There is a reason for this. At that time his mind was teeming with great problems of mechanics, and then in 1609 he invented the telescope, which opened up marvels of the heavens hitherto undreamt-of, and these practically absorbed the next 20 years of his life.

During the long summer vacations at Padua, where he was professor, Galileo was wont to spend his holidays in Florence, where, from about 1601, he gave private lessons on the sciences to young Prince Cosimo de Medici. In the summer of 1607 he had been rehearsing the wonderful properties of loadstones, and, having inspired his pupil with a desire to possess one, he, on returning to Padua, was able to send him a specimen, which he had "picked up" in Venice, about half a pound in weight, not elegant in form, but very powerful. "A friend [Sagredo, as it later transpired] had another fine stone beautifully shaped and weighing about five pounds, which might be had—at a price." Later, early in 1608, he refers to this stone, and adds: "The marvellous thing about it is, not that it weighs so little, but that it holds more than its own weight, or $5\frac{1}{2}$ pounds of iron, as I have made it do in the last few days, and I believe that I can make it hold still more before it leaves my hands. It requires experience to develop its full power, as the points or poles where the virtue is most robust are two and only two, and these must be found with diligence. Then, the sustaining force depends as much on the quality of the armature as on the stone itself, as not every kind of iron and not every size and shape are equally supported, but highly wrought steel is most powerfully attracted. I have already made this stone to carry a pound more than its owner was ever able to do, and I hope after preparing some pieces of finest steel to make it hold very much more."

He goes on to describe, for the first time on record, an interesting case of what is sometimes called "superposed magnetism": "I have also observed in this stone another admirable property which I have not noticed in any other, namely, that the same pole repels or attracts the same piece of iron according to distance; thus, placing an iron ball on a smooth and level table, and quickly

^{*} "Probably the book would never have come into my hands if a peripatetic philosopher of great fame had not given it to me, as I believe, to free his library from its contagion" ("Dialogo" of 1632.)

presenting the stone at about one finger's distance, the ball moves away and can be chased about at pleasure. But sharply withdraw the stone to a distance of five fingers, the ball now moves towards it, and, with a little dexterity, can be made to follow it about. It never approaches nearer than one finger, at which distance repulsion ensues."*

In due course this stone was secured for Prince Cosimo, and, in a covering letter dated 3rd May, 1608, he says: "I send for his Highness the loadstone, which, after many trials, I have made to hold a weight of 12 pounds, or more than double its own, and this is not the half of its marvellous properties. I have found, not without astonishment, that the stone supports more willingly two weights together, one at each pole, than one of them alone. Thus, a piece of iron, so heavy as not to be borne when applied alone to one pole, will be held if at the same time another piece is applied to the other pole.† I have in mind some other artifices to render the stone still more powerful, and I am certain that I shall not fail, but I have not the means of doing so here. I believe I can make it sustain 4 times its own weight, or 20 pounds, which for such a large stone is something very admirable. Indeed, I have no doubt that with proper cutting it can be made to support 30, even 40 pounds."

"Another thing I have noticed in regard to this stone is, not only that it never tires of holding a weight, but that with time it invigorates itself, i.e. the longer it sustains a weight the more it gains in strength, and the more weight it can carry."‡

Galileo's "other artifices" referred to above consisted in breaking up large stones, shaping the best pieces so as to bring out their maximum of polarity, and providing them with soft-iron armatures, with the result that the portative force of the selected pieces greatly exceeded his own first successes, and far surpassed Gilbert's achievements in the same direction. Thus, in chapter 17, Book II, of the "De Magnete," the English philosopher speaks of a stone (weight not given) which normally could sustain 4 ounces, "but," he goes on, "the greatest force of a combining or rather united nature is seen when two stones, armed with iron caps, are so joined by their concurrent (commonly called contrary) ends that they mutually attract and raise one another. In this way a weight of 20 ounces of iron is raised, when either stone unarmed would allure only 4 ounces."

Now, Galileo went far beyond this, since he was able by his "other artifices" to fashion small stones of extraordinary power. Thus, there is preserved in the University of Padua (cabinet of physical science) a stone armed by him. It weighs 21 ounces and supports 100 ounces. Of another small stone he speaks in a letter to Cesare Marsili, dated 27th June, 1626; it weighed 6 ounces and unarmed could support 1 ounce only, but when suitably armed it was able to hold 150 ounces, or 25 times its

own weight. He had it by him when writing his famous "Dialogo" of 1632, and later presented it to the Grand Duke of Tuscany. It is now preserved in the Tribuna di Galileo in Florence* (see Plate 5).

Section 2.

STATIC (OR FRICTIONAL) AND ANIMAL ELECTRICITY.

EARLY KNOWLEDGE.

The science of electricity, like that of magnetism, is a comparatively modern creation, dating only from the beginning of the 17th century. "The vast discoveries," says Lardner, "which have accumulated respecting this extraordinary agent . . . are exclusively due to the spirit of modern research, and in a great measure to the labours of the present age."

Yet it is not that Nature had concealed her secrets with more than her usual coyness, for we find scattered through the writings of the ancients many observations on a class of phenomena which, if rightly examined, must have led to the establishment of electricity as a department of physics. That amber acquires by friction the power of attracting light bodies, such as bits of straw, wood, and dry leaves, is a fact which is, probably, as old as the discovery of the substance itself. Thales described the property 600 years B.C., and not as if it were a new phenomenon, but rather as a familiar illustration of his belief in a living principle, a soul, in all things, which in this case can be roused by friction. Aristotle, Pliny, and other Greek and Roman writers also record the fact, and sometimes mention luminous appearances attending the friction. Theophrastus, 321 B.C., speaks of the *lapis lycuarius*, supposed to be our modern tourmaline, as possessing the same property, adding that it attracts not only straws and leaves, but copper and even iron if they be in small particles. The emission of sparks from the human body, when submitted to friction, had also been noticed, as in the case of Servius Tullius, the sixth king of Rome, whose locks were often observed to give off sparks under the operations of the toilette. In the pages of Cæsar, Livy, and Plutarch, there are to be found frequent allusions to flashes at the points of the soldiers' javelins, at the tops of the masts of ships, even on the heads of the sailors themselves, now assumed to be electrical, but then regarded as manifestations of the gods. In the early ages of the church the popes were often regarded as magicians. Gregory VII, the terrible Hildebrand who brought Henry, the German Emperor, to his knees at Canossa (1077), was held in especial awe, because when he pulled off his gloves fiery sparks issued from them. Eustathius, Bishop of Thessalonica, A.D. 1160, cites

* It was probably while "searching for loadstones amongst the antiquaries of Venice," that Galileo fell in with one of those peripatetic vendors of magnetic telegraphs (so numerous in the 16th and 17th centuries) of whom he gives us a characteristic account. In the dialogue just mentioned he makes Sagredo say, "You remind me of one who offered to sell me a secret art, which, by a certain sympathy between magnetized needles, would enable me to speak to one who might be two or three thousand miles away. I told him that I would become the purchaser willingly, provided only that I might first make trial of the art, and that it would be sufficient for this purpose if I place myself in one room and he in another. He replied that in so short a distance the action would be hardly discernible; whereupon I dismissed the fellow, saying that it was not convenient for me just then to go to Cairo or Muscovy, but that if he chose to go there himself I would remain in Venice and attend to the rest."

* Subsequent experiments showed that the ball was not pure iron but of the nature of magnetized steel. Cf. Jules Jamin in *Comptes Rendus*, November 1875.

† This acute observation occurs also in Gilbert's "De Magnete," Book II, chap. 22. "Even now," says Silvanus Thompson, "this fact is not as well known as it ought to be. Only so recently as 1861 Siemens patented the device of fastening a mass of iron to one end of an electromagnet in order to increase the power at the other end" ("Notes on the De Magnete").

‡ Unfortunately, the Sagredo stone and the smaller one "picked up in Venice" were lost in after years. In 1699 Leibnitz searched for them in vain in Florence.

another case, that of a certain ancient philosopher, from whom, when changing his dress, sparks were emitted accompanied by crackling noises.

The Greeks and Romans were not the only people of antiquity to whom these phenomena were familiar. In the writings of Knopho, a Chinese physicist of the 4th century A.D., we read: "The attraction of amber for the small grains of mustard seed is like that of a magnet for iron. It is like a breath of wind which mysteriously penetrates both, and communicates itself with the rapidity of an arrow." In the Persian language amber is called *Kárubá* or attractor of straw; as the magnet is called *Ahanruba* or attractor of iron. In the old Persian romance, "The Loves of Majnoon and Leila," the lover says of his adored one: "She was as amber and I but as straw, she touched me and I shall ever cling to her." Humboldt, after referring to facts such as these, tells us how he observed with astonishment on the woody banks of the Orinoco, in the sports of the natives, that the excitement of electricity by friction was known to these savage races. Children might be seen rubbing the dry, flat, and shining seeds or husks of a trailing plant until they were able to attract threads of cotton and pieces of bamboo cane.

WORK OF WILLIAM GILBERT.

Without going the length of asserting that electrical phenomena were entirely neglected in Europe during the Middle Ages, it seems certain that, with the exception of the discovery of the electrical property of jet, no advance was made up to the close of the 16th century. Then it was that Dr. Gilbert of Colchester for the first time collected the scattered fragments and, with many additions of his own, shaped them into the nucleus of a new science, to which he gave the name "Electricity." In his great work, "De Magnete," he described the only three substances known up to his time as susceptible of electrical excitation, and added a number of others, such as spars, jems, fossils, sulphur, glass, and resin, which displayed the property of attracting, not only light bodies like feathers and straws, but all solid and fluid matter, as metals, stones, water and oil.

He also observed some of the circumstances which affect the production of electricity, such as the hygro-metric state of the atmosphere. Thus, he noticed that when the wind blew from the north or east, and was dry, a body could be excited by a brisk friction, but that when the wind was from the south and moist the excitation was difficult and sometimes impossible. In order to test the condition of the bodies experimented upon, Gilbert made use of a light needle of any metal balanced and turning freely on a pivot, to the extremities of which he presented the bodies after excitation. Some of his deductions were curiously fallacious. In pointing out, for instance, the distinction between magnetic and electric attraction, he affirmed that magnets and iron mutually attracted, but that when an electric was excited, it alone exercised the force, the body attracted remaining inactive. Again, as a special distinction, he held that magnetism repelled as well as attracted, whilst electricity attracted only.

Gilbert's views as to the cause of electrical manifesta-

tions differed materially from his conception of magnetic action. In the latter case he assumed boldly an "Orbe of Virtue" around the magnet, within which magnetic effects take place. In the former case he adhered to the schoolmen's view, and supposed the phenomena to be the result of an effluvium thrown out by the electric body. "All electric attraction," he says, "exists through an intervening humour, which must be very rare, so that it may the better permeate the medium. If it be too gross, as that of air or the wind, it will drive everything before it, but these very rare effluvia take hold of bodies, embrace them as with extended arms, and draw them to the source."

The few references to electricity in the works of Sir Francis Bacon, Nicolas Cabeus, Kenelm Digby, Gassendi, Descartes, Thomas Browne, and others may be passed over in silence, as they are chiefly theoretical, and did not contribute in any way to the advancement of the science.

PROGRESS IN THE 17TH CENTURY.

The celebrated Robert Boyle (1626-1691), as a boy of 11 years, left England with an elder brother to pursue his studies abroad under the care of a French tutor. Travelling through France they made a long stay in Geneva, then passed into Italy and, after visiting Venice and other famous places in the north, spent a whole winter in Florence, the home of the illustrious Galileo. Considering the disparity of age (78 and 16 years) it is not likely that the two men ever met, but we cannot tell how much of the young student's love of experimental philosophy may have been due to his accidental residence in a place where the renown of Galileo and his works was fresh in the minds of all. Returning to England in 1644, Boyle soon took a prominent place among the immortals in science, and became one of the first members of an association which was afterwards incorporated as the Royal Society (1663), and of which he was offered the presidency in 1680, an offer which he declined (like Faraday 150 years later) on conscientious grounds. His special study was pneumatics, but he gave some attention to electricity, and has left us an account of his experiments in a small work, "Experiments and Notes about the Mechanical Origine or Production of Electricity" (London, 1675). By means of a suspended needle, he discovered that amber retained its attractive virtue for some time after the friction ceased, and, though smoothness of surface had been regarded as advantageous for excitation, yet he found a diamond in its rough state to exceed all the polished ones and all other electrics that he had tried, since it was able to move the needle 3 minutes after he had ceased rubbing. He found also that heat and "tersion" (i.e. wiping a body) increased the electrical effect, and that, if the attracted body were fixed and the attracting one movable, their approach would take place all the same, thus disproving one of Gilbert's deductions. To Gilbert's list of electrics he added several new names, as glass of antimony, white sapphire, white amethyst, and cornelian.

Boyle is sometimes said to have been the first in modern times to observe the electric light—an assertion which seems to be based on his observation in 1663 of

the light which rubbed diamonds gave out in the dark. But it is doubtful whether this was not an optical rather than an electrical effect, belonging to the class of phenomena of which the celebrated Bologna stone of the *quondam* shoemaker Casiorolus (1602) was the first recorded example, just as Balmain's luminous paint is the last.

Like all his predecessors, Boyle speculated in his turn on the cause of electrical phenomena, but he, as well as they, could find no better explanation than that offered by the Ionic sage 23 centuries before. He supposed that the excited body threw out a glutinous or unctuous effluvium, which laid hold of small bodies in its path, and on returning to its source carried them along with it. The *Philosophical Transactions* of this period contain some learned disquisitions in support of this idea, and experiments are described which were considered conclusive of its correctness. Hence arose the fashion of ascribing to "humours," or "fluids," or "effluvia," those physical conditions which could not otherwise be accounted for.

Otto von Guericke, burgomaster of Magdeburg and inventor of the air pump, was contemporary with Boyle, and to him we owe some important advances. In 1671 he constructed the first electrical machine, by means of which he was able to produce electricity in far greater quantities than had hitherto been possible from the friction of glass or sulphur rods. With this machine, which consisted of a globe of sulphur mounted on a rotating axis, and excited by the friction of a cloth held in the hand, he discovered "the hissing noise and gleaming light" which result from strong electrification.*

To him belongs the discovery of the property of electrical repulsion. He observed that a feather, when attracted by an excited electric, was instantly repelled, and was incapable of a second attraction until it had been touched by the finger or some other body. He also noticed that a feather when thus repelled always kept the same side towards the excited electric—a fact which, being like the behaviour of the moon in relation to the earth, induced him to assume that the revolution of the moon round the earth might be explained on electrical principles. Again in his observation that a substance becomes electric by being brought near to an electrified body, von Guericke discovered the fact, though not the principle, of induction.

Newton (1642–1727) about the same time published another effect of induction. One side of a glass plate being electrified, he found that the other side was also electrified and would attract light bodies within its influence. Laying upon a table a disc of glass 2 inches broad, raised by a brass hoop or frame about $\frac{1}{2}$ inch from the table, and then rubbing it briskly, bits of paper under the glass moved nimbly to and fro, and twirled about in the air, these movements continuing for a considerable time after he had ceased rubbing. Upon sliding a finger over the glass, though he did not agitate either it or the air beneath, he observed that the papers,

as they hung from the underside of the glass, would take up some new movement, inclining this way or that according to the direction of his finger.

In the 8th and 27th queries at the end of his treatise on Optics, Newton introduces the subject of electricity in such a way as to convey some notion of his theoretical views. He says in the 8th query: "A globe of glass 8 or 10 inches in diameter being put into a frame where it may be swiftly turned round, its axis will in turning shine where it rubs against the palm of one's hand applied to it, and if at the same time a piece of white paper be held at a distance of $\frac{1}{2}$ inch from the glass the electric vapour, which is excited by the friction of the glass against the hand, will by dashing against the paper be put into such an agitation as to emit light and make the paper appear livid like a glowworm. In rushing out of the glass it will sometimes even push against the finger so as to be felt." In his 27th query he says: "Let him also tell me how an electric body can by friction emit an exhalation so rare and subtle and yet so potent as by its emission to cause no sensible diminution of its weight, and to be expanded through a sphere whose diameter is above 2 feet, and yet to be able to agitate and carry up leaf copper or leaf gold at a distance of above 1 foot from the electric body."

These appear to be the only published observations of the great Sir Isaac on electricity, but it would seem that, in moments of leisure from weightier business, he bestowed an occasional glance on the infant science. This is evident from the following extract from a letter which Latimer Clark unearthed and which will be found in full in the *Electrician* (16th April, 1881): "I have been much amused by ye singular phenomena resulting from bringing of a needle into contact with a piece of amber or resin fricated on silke clothe. Ye flame putteth me in mind of sheet lightning on a small (how very small) scale." This letter is dated from London, 15th December, 1716, but it would seem from the wording that Newton was then unaware of similar comparisons by Hauksbee and Wall several years before

EARLY 18TH-CENTURY WORK HAUKSBEE AND WALL.

Between 1705 and 1711, Hauksbee made many valuable observations, of which we must content ourselves with a brief résumé, referring for fuller accounts to his papers in the *Philosophical Transactions*, or to Priestley's excellent "History and Present State of Electricity," 1767. In 1705 he showed that light could be produced by passing common air through mercury in a well-exhausted glass receiver. The air rushing through the mercury blew it against the sides of the glass, and made it appear like a body of fire, consisting of an abundance of glowing globules. In repeating this experiment with about 3 pounds of mercury, making it break into a shower by dashing against the crown of another glass vessel, flashes resembling lightning, of a very pale colour, and distinguishable from the body of light, were thrown off from the crown of the glass in all directions. Hauksbee likewise showed that considerable flashes might be produced by agitating mercury in a partially exhausted tube; and, even in the open air,

* Sulphur was a favourite electric with early experimenters, as it was supposed that electricity was emitted with the effluvium produced by the friction. In the construction of his machine, von Guericke, for example, cast the sulphur in a glass globe, which he afterwards broke to get at the sulphur, little thinking that the glass globe itself would have answered his purpose just as well.

numerous flashes can be had simply by shaking quicksilver in any glass vessel.*

In a subsequent series of experiments on the light produced by the attrition of bodies *in vacuo*, he showed that glass when thus excited emitted light in as strange a form as lightning, particularly when he used a rubber that had been previously drenched in spirits of wine. In all these experiments Hauksbee had no notion of the electrical origin of the light, and in saying that it resembled lightning he was only using a simile, without any suspicion of a closer connection.

Like Sir Isaac Newton, Hauksbee employed a glass-globe machine. When exhausted of air and turned briskly, the application of his hand would produce a strong light on the inside; and, by readmitting the air, light would appear on the outside also. On bringing an exhausted globe near to an excited one, he found that light was produced in the former and soon disappeared; but on a further excitation reappeared with great beauty of form.

The following experiment was at the time considered to be very singular. Having coated one half of the inside of a glass globe with sealing-wax, which in places was $\frac{1}{8}$ inch thick and quite opaque, he exhausted it and set it in motion. On applying his hand for the purpose of excitation, its outline became visible on the concave surface of the wax, thus making it seem to be transparent, although before excitation it would only just allow the flame of a candle to be seen through it in the dark.

Besides light and crackling noises, Hauksbee noticed that an electrified body was able to cause a sense of pain or shock in the hand or face that touched it.†

Dr. Wall shares with his friend Hauksbee the credit of noticing the sense of pain or shock from an electrified body. This philosopher is, however, best known as being the first to suspect the identity of electricity and lightning. The thought was suggested, as he tells us in a paper read before the Royal Society in 1708, by the sparks and crackling sounds produced by the friction of a large stick of amber against a woollen cloth. "Upon drawing," he says, "the amber swiftly through the cloth and squeezing it pretty hard with my hand, a prodigious number of little cracklings was heard, every one of which produced a little flash of light; but when the amber was drawn slowly and lightly through the cloth there was light but no crackling. By holding a finger at a little distance from the amber, crackling ensues followed by a great flash of light, and, what is very surprising, it strikes the finger sensibly with a push or puff like wind. The crackling is full as loud as that of charcoal on fire; nay, five or six cracklings or more, according to the quickness of placing the finger,

* Electric light *in vacuo* was first observed by Picard in 1675 while carrying a torricellian tube from the Observatory to Porte St. Michel in Paris. Sébastien, Cassini, and John Bernoulli (1700) are credited with similar observations. After Hauksbee (as in the text), Grummert noticed that an exhausted tube presented to the conductor of an electrical machine was traversed by a flash of

exhausted in a tube 3 feet long, exhausted to a high degree by means of Smeaton's improved form of air pump. Morgan in 1775 created a vacuum sufficiently high to be non-conducting, and observed a green fluorescence on admitting a little air. Indeed, Morgan may be said to have generated X-rays, but of course without realizing it. Finally, Davy in 1822 showed that a really powerful electrical machine could discharge through the highest vacuum obtainable in his day.

† For a clever imitation of Hauksbee and his method, see a lecture—surely unique in the annals of science—by Prof. Andrade, reported in the *Times* of the 5th January, 1927.

have been produced from one single friction, light succeeding each crack. Now I doubt not that, on using a longer and larger piece of amber, both the cracklings and the light would be much greater. This light and crackling seem in some degree to resemble thunder and lightning."

SYSTEMATIC INVESTIGATION BEGUN: STEPHEN GRAY.

So far, experimenters had worked without a system, and without wholly comprehending the principles on which their effects depended. Important as were all these results, yet the true foundations of electricity as a science cannot be said to have been laid until Stephen Gray, a pensioner, of the Charter House, gave to the world that celebrated series of experiments which, begun in 1720, ended with his last breath in 1736. As from this point the domain widens, we will confine ourselves in the rest of this Section to noticing only such discoveries of Gray and succeeding philosophers as bear upon our subject.

In February 1729 Gray discovered the principles of electric conduction and insulation. Wishing to excite in metals, as had already been done in glass, resin, etc., the power of attraction and repulsion, he tried various methods, such as rubbing, heating, and hammering, but all to no end. At last it occurred to him that, as a glass tube when rubbed in the dark communicated its light freely to bodies, so it might communicate a power of attraction, which at this time was considered the absolute proof of the presence of electricity. In order to test this he took a glass tube, 3 feet 5 inches long and 1 inch diameter, and filled up the ends with pieces of cork to keep out the dust. His first experiment was to see if there was any difference in its power of attraction when the tube was stopped at both ends and when left open, but he could perceive no sensible difference. Then, holding a feather near to one end of the tube, he saw it fly to the cork, being attracted as strongly as by the tube itself. He concluded from this that the electric virtue conferred on the tube by friction passed spontaneously to the cork.

It then occurred to him to inquire whether this transmission would be made to other substances besides cork. He took a deal rod 4 inches long, to one end of which he attached an ivory ball and inserted the other in the cork. On exciting the tube he found that the ball attracted and repelled the feather even more vigorously than the cork. He then tried longer rods of deal, and lengths of brass and iron wires, with like results. Finally, he attached to one end of the tube a length of common packthread, and suspending from its lower end the ivory ball and other bodies, found that all of them acquired the electric state when the tube was excited.

In true philosophic spirit he now set himself to ascertain what circumstances attending the manner of experimenting produced any differences in the results, and first whether the position or direction of the rods, wires, or threads affected the phenomena. He laid out a packthread in a horizontal direction, supporting it at points by pieces of similar material, attached to nails driven into a wooden beam, so that the supporting threads were in a vertical position. To one end of the thread

he attached the ivory ball and tied to the other the end of the tube. On exciting the latter there was no effect on the ball, which he rightly ascribed to the escape of the electricity by the vertical threads, the nails supporting them, and the wooden beam.

DISCOVERY OF INSULATORS.

On the 30th June, 1729, Gray was repeating these experiments at the house of Mr. Wheeler (afterwards associated with him), when that gentleman suggested that threads of silk be used to support the horizontal line instead of packthread. It does not appear that this suggestion proceeded from any suspicion of the electric property of silk, and still less that Gray was acquainted with it, for in assenting to the proposal he observed that silk might do better than packthread on account of its thinness, as probably less of the virtue would pass off by it than by thick hempen supports. Accordingly on the 2nd July, 1729, they laid out a packthread for a distance of 80 feet in a horizontal position, supporting it at intervals by threads of silk. To one end they attached the ivory ball and to the other the glass tube. When the latter was excited the ball showed signs of electrification by attracting metallic leaf held near it. Next day with a still longer packthread the silk supports proved to be too weak and broke. Supposing that the escape of the electricity was prevented by the fineness of the silk, they now substituted thin brass wire, which, being still finer than the silk, should, they thought, be more effectual in intercepting the electricity. The experiment failed completely. No signs of electricity passed to the ivory ball. It escaped through the wire supports notwithstanding their fineness. They now concluded that the silk threads intercepted the electricity because they were silk, and not because they were fine.

Having thus discovered the property of insulation they proceeded to its generalization, and found that it was shared by resin, hair, glass, and other substances. In fact, it was soon found that in this respect all matter belongs to one of two classes, the one like the thread and wire favouring the dissipation or carrying-away of the electric power, and the other like the silk opposing it. Armed with this knowledge Gray and Wheeler, in July 1729, were able to transmit the electric power through 765 feet of packthread supported by silken loops; and 12 months later through 886 feet of wire. It is curious to observe that in these experiments, as, indeed, in all on electrical conduction, we have the essentials—crude, of course—of an electric telegraph; the insulated line, the source of electricity in the rubbed glass, the indicating instrument in the down feather, and the earth or return circuit, the function of which, however, was not then suspected.

In August 1729 Gray noticed that when the rubbed tube was brought near to any part of a non-electric or conducting body the part most remote from the tube showed signs of electricity. He thus fell upon the fact which afterwards led to the principle of induction. The science, however, was not yet ripe for that great discovery, and Gray, like Otto von Guericke and Newton before him, and Wilson and Canton after him, continued to note the fact without a suspicion of its

significance. The elucidation was to be one of the achievements of Franklin many years later.

In his last paper, read before the Royal Society in 1735, Gray has some prophetic visions. Speaking of the fire and explosion of electricity communicated to a metal rod he says: "Though these effects are at present very minute, yet it is probable that in time there may be found a way to collect a greater quantity of the electric fire and consequently to increase its force, which, by several of these experiments if we are permitted to compare small things with great, seems to be of the same nature with that of thunder and lightning."

While Gray and Wheeler were pursuing their investigations in England, Dufay, of the Academy of Sciences and Intendant of the Royal Botanic Gardens, was independently engaged in Paris in similar pursuits. The researches of this philosopher, celebrated as the originator of the two-fluid theory of electricity, embraced the period between 1733 and 1737. He added largely to the class of bodies called "electrics" by showing that all substances, except metals and bodies in the soft or liquid state, might become electric by heating them and then rubbing them on any kind of cloth; and as regards these exceptions he found that they, and generally all bodies, solid and liquid, could be electrified by the simple precaution of first placing them on glass stands.

In repeating Gray's experiments with packthread, he found that they succeeded better after wetting the line, and he was thus able to transmit the electric power along a 1300-foot cord supported at intervals on glass tubes.

DISCOVERY OF THE TWO KINDS OF ELECTRICITY.

His discovery of the dual character of electricity was, like many previous discoveries, entirely owing to chance. A piece of gold leaf having been repelled by an excited glass rod, Dufay pursued it with an excited rod of sealing-wax, expecting that the result would be the same. His surprise was great on seeing the gold leaf fly to the wax, and on repeating the experiment many times the same effect invariably followed. The gold leaf when repelled by excited glass was attracted by excited resin, and vice versa. Hence he concluded that there are two kinds of electricity, that produced by friction of glass he called "vitreous" and that from the friction of resin "resinous."

In repeating Otto von Guericke's experiments Dufay discovered another general law, which enabled him to explain a number of observations that hitherto had been obscure. This law states that an electrified body attracts all those that are not so, and repels them when they become electrified by contact with itself. Thus, gold leaf is first attracted by the excited tube, and acquires by contact electricity of the same kind, whereupon it is repelled.

FURTHER EXPERIMENTS IN TRANSMISSION.

The study was next taken up in 1737 by Desaguliers, who, born in France in 1683, early removed to England and died in London in 1744. Two years before death he published his "Dissertation Concerning Electricity," which is interesting as being the first book on the subject in the English language. Desaguliers' investigations were mainly concerned with the conducting powers of

various bodies; but he did useful work otherwise, by classifying the information that had already accumulated and by improving in some respects the nomenclature. Thus, the labours of Gray, Wheeler, Dufay, and himself had shown that all matter was divisible into two great classes: these he now proposed to call "electrics," or bodies in which electricity could be excited by friction; and "non-electrics," or those incapable of excitation, but which could receive a charge from an electric. He also was the first to use the words "conductor" and "non-conductor" in the same sense as that in which we use them to-day.

In the *Philosophical Transactions* for 1739 will be found his experiments on the transmission of electricity made at the Prince of Wales's house at Cliefden. Having heard that electricity had been carried along a hempen string of 500 or 600 feet, but having seen it done only when the string was carried backwards and forwards in a room and supported by silk threads, Dr. Desaguliers wished to try it with a packthread stretched out at full length. Having joined a piece of catgut to one end of the thread he fastened it to a door. Tying another catgut to the other end of the thread he fastened it to a distant part of the house. At the places where the thread was joined to the catguts he left 18 inches of the thread hanging down, and tied a *lignum vitæ* handle of a burning glass to one, while he applied a rubbed tube to the other. To test whether a body was electrified he brought near to it a "thread of trial" which was a thread hanging from a wooden handle. He made the electricity run to the *lignum vitæ* with some difficulty, which he attributed to the sizing that still adhered to the (new) thread. He wetted the thread from end to end and washed off the sizing; then only was the electricity from the tube transmitted, and very strongly, for the hanging "thread of trial" was drawn by the *lignum vitæ* at a distance of 1 foot.

"Can Britain . .

. . . permit the weeping muse to tell
How poor neglected Desaguliers fell?
How he who taught two gracious kings to view
All Boyle ennobled, and all Bacon knew,
Died in a cell, without a friend to save,
Without a guinea, and without a grave!"—

CAWTHORN,

"The Vanity of Human Enjoyments."

IMPROVEMENTS IN ELECTRIC MACHINES.

Up to this time, and until some years later, experiments on the transmission of electricity to a distance excited no attention outside a narrow circle of scientific men, and even amongst these they served only to illustrate the two great electrical properties of bodies—conduction and insulation—without evoking a suspicion of their practical value. The whole subject, however, now began to attract attention, especially amongst the Germans, and the first results were considerable improvements in the power and efficiency of electrical apparatus. About 1741 Professors Hansen, of Leipsig, and Bose, of Wittemburg, revived the use of the glass-globe machine of Newton and Hauksbee, which, after their time, had been supplanted (to the detriment of the science) by

the glass tube and silk rubber of Gray. Bose also added the prime conductor, consisting of an oblong cylinder of tin or iron. This was at first held in position by a man who was insulated by standing on cakes of resin, but later it was suspended by silken cords, and in order to facilitate the passage of electricity a number of linen strings were added, which served the purpose of the metal points now employed. Prof. Winkler of Leipsig substituted a fixed woollen cushion in place of the hand, and lastly, in 1742, Gordon, a Scotch Benedictine monk and professor of natural philosophy at Erfurt, substituted a glass cylinder for the glass globe of Newton and otherwise increased the power of the machine so that he was able to kill small birds at the end of an iron wire 200 ells (750 feet) long.

INVENTION OF THE LEYDEN JAR AND CONDENSER.

These improvements were followed in October 1745, by the invention of the Leyden jar. This is one of the vexed questions of the science, its invention being claimed, and perhaps with equal justice, for von Kleist, dean of the Cathedral at Kamin in Pomerania, for Cuneus, a rich burger of Kamin, and for Musschenbröck, the celebrated professor of Leyden. Von Kleist was first in point of priority of publication, but his account is so obscurely worded that it was impossible for some time to verify it.*

In January 1746 Cuneus made the same discovery, and in the same accidental way. It having been observed by Musschenbröck and his colleagues (Cuneus and Allamand) that electrified bodies speedily lost their virtue, which was supposed to be abstracted by the air and by vapours and effluvia suspended in it, they imagined that if they could surround them with an insulating substance, so as to exclude the air, they could communicate a more intense electrical power and could preserve that power for a longer time. They tried the effect of electrifying water contained in a glass bottle. At first no remarkable results were obtained. But on one occasion Cuneus happened to hold the bottle in his right hand while the water communicated by a wire with the prime conductor of a powerful machine. When he thought that the water was sufficiently charged, he proceeded to disengage the wire from the machine with his left hand. Instantly he was struck by a violent shock which filled him with consternation and made him let fall the flask. Musschenbröck and others repeated the experiment and with like results.

In a letter to Réaumur, Musschenbröck said he felt himself struck in the arms, shoulders, and chest so that he lost his breath, and it was two days before he recovered from the effects of the blow and the terror. He added that he would not repeat the experiment for the whole Kingdom of France. Bose, on the other hand, coveted electrical martyrdom, for he is said to have wished to die by the shock, so that it might furnish an article for the memoirs of the French Academy. Allamand took the shock from an ordinary beer glass, lost his breath for some moments, and then felt so intense a pain in his right arm that he feared permanent injury. Prof. Winkler, on making the experiment for the first time,

* See Dr. Lieberkuhn's letter of the 4th November, 1745, to the Berlin Academy

suffered great convulsions, his blood was agitated and, fearing an ardent fever, he had recourse to cooling medicines. His wife, also, with a courage equalled by her curiosity, twice subjected herself to the shock, and was so shaken that she could hardly stand, and on trying again a week later it gave her bleeding at the nose.

An account of these extraordinary effects soon got abroad. The experiments were repeated everywhere, and called forth the wonder of all classes towards what was regarded as "a prodigy of nature and philosophy." Indeed, so popular did they become that great numbers of soi-disant electricians wandered over Europe and enriched themselves by gratifying the universal curiosity at so much per shock. But as soon as these feelings had abated, philosophers set themselves seriously to study the powers of the new machine, and the circumstances which influenced the force of the shock first engaged their attention.

Musschenbroek noticed that if the glass be wet on the outer surface the effect is greatly impaired. Dr. (afterwards Sir William) Watson, apothecary and physician of London, next proved that the force of the shock was increased by diminishing the thickness of the glass, and, further, that it depended on the extent of the external surface of the glass in contact with the hand. It next occurred to Dr. Bevis that the hand was efficient only as a conductor, and in that case that the objective might be more conveniently attained by coating the exterior of the phial with sheet lead or tin-foil. This expedient was completely successful, and the phial, so far as related to its external surface, assumed its present form.

Another important advance was also due to Dr. Bevis. It appeared that the force of the charge increased with the size of the jar, but not in proportion to the amount of water it contained. It was thought that it might depend upon the extent of glass in contact with the water, and, that as the water merely played the part of conductor, a better conductor such as a metal would be at least equally efficient. Three phials were now procured and filled to the usual height with shot, and a metallic contact was made between the shot in the three phials. The result was a charge of greatly increased force. This, in fact, was the first Leyden-jar battery. Dr. Bevis now saw that the seat of the electricity was the surface of contact of the metal and the glass, and rightly inferred that the form of a bottle or phial was not essential. He took a pane of common glass and, coating both sides with tin-foil to within 1 inch of the edges, obtained as strong a charge as from a phial with the same extent of coated surface. Dr. Watson, being informed of this, coated large jars of thin glass inside and outside with silver leaf and nearly to the top of the jars. The results corroborated fully those of Dr. Bevis, and established the law that the "force" of the charge was proportional to the extent of coated surface and to the thinness of the glass.

EXPERIMENTS WITH CONDENSERS: VELOCITY OF TRANSMISSION.

Experiments on the transmission and velocity of electricity, to which the new discoveries lent fresh interest, were now resumed. Daniel Gralath in 1746

was the first to transmit the shock to a distant point by discharging a battery of several jars through a chain of 20 persons with outstretched arms. A little later Joseph Franz in Vienna discharged a jar through 1 500 feet of iron wire, and, in the following July, Winkler charged and discharged a battery of three jars through an insulated wire 112 feet long, laid along the bank of the river Pleisse, the waters of which formed the return half of the circuit. Winkler had previously ascertained that the rapidity of an electric discharge was exceedingly great and comparable with that of lightning. He also believed "that electricity could be transmitted to the ends of the earth if a conducting body insulated with silk covering be laid so far, it being only necessary to consider that there may be a certain amount of resistance to the transmission to be overcome."

The Abbé Nollet, whose name is famous in the annals of this period, had meanwhile taken up the subject in France. He first transmitted, in April 1746, the shock of a Leyden jar through a chain of 180 of the Royal Guards in Paris, to the delight of Louis XV, who witnessed the experiment; and soon after he arranged a grander experiment of the same kind at the Carthusian convent. By means of iron wires stretched between the monks he formed a circle of 5 400 feet through which he discharged his jars, with the result that at the moment of discharge all the persons in the circuit gave a sudden spring showing that the shock was felt by each at the same instant and to the same degree of intensity.*

Lemonnier the younger, also of Paris, made use of still longer circuits of 2 000 toises (12 700 feet) of iron wire laid along the ground; and although some of the wire lay upon wet grass, through hedges, and over newly ploughed fields, the shock was in no way diminished, a fact thought very surprising. In other experiments he made use of two large basins of water in the Tuileries gardens. In April 1746, in the Court of the Carthusians, he laid two wires, each 5 700 feet long, in parallel circles so that all four ends were close together. Between one pair he placed a jar and grasped the other extremities himself, then on closing the circuit he could not distinguish any interval between the spark at the jar and the shock through his arms.

Upon receiving an account of these experiments from Lemonnier, Dr. Watson took up the inquiry in London, and pursued it so successfully as not only to eclipse the achievements of his neighbours, but to gain for himself in after years the credit of being the first to propose an electric telegraph—a claim which is entirely baseless. Watson's experiments were numerous and were carried out under the auspices of a Committee of the Royal Society. He published a full account of his labours in 1748, in which he tells us that his first trials took place on the 14th and 18th July, 1747, on a wire carried from one side of the Thames to the other over old Westminster Bridge. The near end communicated with the interior of a charged Leyden jar; the other or far end was held by a friend in one hand while in the other he held an iron rod which he dipped into the water. Beside the jar stood another friend, holding in one hand a wire connected with the exterior coating of the jar and in the other an iron rod. On dipping this into the river

* For an interesting example of Nollet's method, see Plate 6.

(thus completing the circuit) the shock was felt by both persons, but more strongly by him who stood by the jar, because, as Watson rightly surmised, part of the outgoing electricity escaped down the moist stonework of the bridge, thereby making several short-circuits beyond the jar, but all passing through the observer who stood by it.

The next attempt was to force the shock through a circuit of 2 miles at the New River, near London. This was done on the 24th July at two places. At one the distance by land was 8 000 feet and by water 2 000 feet, and at the other 2 800 feet of land and 8 000 feet of water. The arrangement of the apparatus was similar to that at Westminster Bridge, and the results were equally satisfactory. Other experiments followed on the 28th July, when for the first time the wire was supported throughout its whole length by dry sticks; and on the 5th August at the Highbury Barn, when it was shown that dry ground conducted the electric virtue quite as well as water.

Finally, on the 14th August, at Shooter's Hill, it was arranged "to try whether the electric shock was perceptible at twice the distance to which it had yet been carried over ground perfectly dry and where no water was near, and also to distinguish if possible its velocity as compared with that of sound." The circuit consisted of 2 miles of wire over 2 miles of dry ground, where only one shower of rain had fallen in the previous 5 weeks. The wire from the inner coating of the jar was 6 732 feet long and was supported upon baked sticks, and that communicating with the outer coating was 3 868 feet long and similarly insulated. The observers placed at the ends and 2 miles apart were provided with stop-watches. The result was that "as far as could be distinguished the time at which the electric force performed its circuit might have been instantaneous."

Not satisfied with this result, the inquiry was resumed in the following year, when trials were made after the manner of Lemonnier's Carthusian experiment. On the 5th August, 1748, a circuit of 2 miles was formed at Shooter's Hill by several turnings of wire in the same field. The middle of this wire was led into a room in which was a Leyden jar, and there Watson placed himself in the centre of the line, taking in each hand the ends of the wire, and noting the spark with his eye while he felt the shock in his arms. Under these conditions the jar was discharged several times, but at no time could he distinguish the slightest interval of time between seeing the spark and feeling the shock. Whereupon it was decided that the time occupied by the passage of electricity along 6 138 feet of wire was altogether inappreciable.

Notwithstanding the suggestiveness of all these experiments, no one up to this time appears to have entertained a suspicion of their applicability to telegraphic purposes, or indeed to any purpose whatever. Thus, Watson says: "If it should be asked to what useful purposes the effects of electricity can be applied, it may be answered that we are not yet so far advanced in these discoveries as to render them conducive to the service of mankind, but future philosophers may deduce from them uses extremely beneficial to society in general." This was in 1746, and had reference to his

recent ignition of spirits by the spark; but even after his brilliant experiments in the following years he does not appear to have formed any more hopeful view.*

THE SECOND HALF OF THE 18TH CENTURY.

BENJAMIN FRANKLIN.

Benjamin Franklin (1706–1790, see Plate 7) in America took up the subject of electricity about 1747 at the comparatively late age of 41, and for some years gave his results to the world in letters to his friend Peter Collinson in London, who communicated them to the Royal Society. At first they were not appreciated—"ignored or laughed at" as the story goes—but he was soon rewarded with a Copley Medal (in 1753) and was elected "F.R.S." in 1756.

His study of the Leyden jar was a brilliant piece of analysis and it completed the theory of that valuable invention. He charged a jar in the usual way and then, insulating it, removed the cork and wire by which the electricity was conveyed from the machine to the inside of the jar. On examining these he found them free of charge. He next carefully decanted the water into another insulated vessel and found it also free of charge. Fresh water was now put into the jar; then, placing one hand on the outside coating and the other in the water, he received the shock as strongly as if no change had been made since the jar was first charged, showing conclusively that the charge resides, not in the water or in the coating, but on, or in, the glass itself.

In 1748 he performed his celebrated experiments across the Schuylkill at Philadelphia, as did De Luc some months later across the Lake of Geneva. Franklin playfully refers to his experiments at the end of a letter to Peter Collinson: "Chagrined a little that we have hitherto been able to produce nothing in this way of use to mankind, and the hot weather coming on when electrical experiments are not so agreeable, 'tis proposed to put an end to them for this season somewhat humourously in a party of pleasure on the banks of the Schuylkill. Spirits are to be fired by a spark sent from side to side through the river, *without any other conductor than the water*—an experiment which we some time since performed to the amazement of many. A turkey is to be killed for our dinner by the electrical shock, and roasted by the electrical jack before a fire kindled by the electrical bottle, when the healths of all the famous electricians in England, Holland, France and Germany, are to be drunk in electrified bumpers, under the discharge of guns from the electrical battery."

As the words the author has italicized in the above extract have misled some writers into supposing that Franklin describes an experiment akin to that of telegraphing without wires, the details are here quoted from his "Complete Works" (London, 1806, vol. i, p. 202):—"Two iron rods 3 feet long were planted just within the margin of the river, one on each side. A thick piece of wire with a small knob at its end was fixed on the top of one of the rods, bending downwards so as to deliver commodiously the spark upon the surface of the spirit. A small wire fastened by one end to the handle of the spoon holding the spirit was carried across the river supported in the air by the rope commonly used to hold

* For Lesage's telegraphic experiments of 1782, see Plate 6.

by in drawing ferryboats over. The other end of this wire was tied round the coating of the bottle, which being charged the spark was delivered from the hook to the top of the rod standing in the water on that side. At the same instant the rod on the other side delivered a spark to the spoon and fired the spirit, the electric fire returning to the coating of the bottle through the handle of the spoon and the supported wire connected with them." This experiment was therefore exactly the same as that of Watson across the Thames, the only difference being in the wording. In the latter case the charge is said to go out by the water and return by the wire, and in the former case to go out by the wire and return by the water.

THE ELECTRICAL CHARACTER OF LIGHTNING.

We have already seen that Newton, Hauksbee, Gray, and others, had noticed the resemblance between the electric spark and lightning flashes, but it was left to Franklin to prove their identity by his famous kite-flying experiments of 1752. He begins his account of these by noting the many points of resemblance between electricity and lightning. Flashes of lightning, he says, are generally crooked and waving, and so is a long electric spark; lightning, like electricity, strikes the highest and most pointed objects in its way in preference to others; it takes to the readiest and best conductor; sets fire to inflammable bodies; rends others to pieces; and melts the metals; so does electricity; lightning has often been known to strike people blind; and the same has happened to a pigeon which had received a strong electric shock; in numerous cases lightning has killed animals; and they have also been killed by electricity. While thinking over these points, an experiment of his friend, Thomas Hopkinson, recurred to his mind. This gentleman electrified a small iron ball to which he fixed a needle in the hope that from the point as from a focus he would draw a stronger spark. Greatly surprised at finding that, instead of increasing the spark, the point dissipated it altogether, he mentioned his failure to Franklin. On repeating the experiment the latter found, not only that the ball could not be electrified when a needle was fixed upon it, but that, when the needle was removed and the ball charged, the charge was silently and speedily withdrawn when a pointed wire connected with the earth was presented to it.

Reasoning on all these effects, Franklin conceived that pointed rods of iron fixed above the house-tops might draw from clouds their electricity without noise or danger. "The electric fluid," he says, "is attracted by points; we do not know whether this property be in lightning, but since they agree in all particulars in which we can compare them, it is probable that they agree likewise in this. Let the experiment be made."

It occurred to him that by means of a common kite he might have ready access to the higher regions of the atmosphere. Preparing a large silk handkerchief extended on two cross sticks, he took the opportunity of an approaching thunderstorm and went into a field, where there was a shed proper for his purpose. But, dreading the ridicule which might attend an unsuccessful experiment, he kept his design from everybody except his son, who helped him in flying the kite. Some time

elapsed without any result, and a promising cloud passed over the kite with no effect. Then, just as he was beginning to despair, he noticed some loose threads upon the kite string begin to diverge and stand erect. He now fastened a key to the string and on presenting his knuckle to it was gratified by the first electric spark that had been drawn from the clouds; other sparks followed; and when the string was wetted by falling rain, a copious stream of fire passed from the key to his hand. On this he "uttered a deep sigh and wished that the moment were his last."

Later Franklin fixed an insulated iron rod on the top of his house and led it down to his study, where it terminated in a little ball of metal. As an alarum, at a little distance from the ball on the rod he hung another ball, insulated and freely suspended, and at the same distance and in the same direction he fixed a small bell connected by a wire with the ground. Now, whenever lightning "struck" the elevated rod, the suspended ball in his study was attracted to the rod, received a charge from the clouds, and was instantly repelled, striking the bell, and giving up to it its charge, which passed silently and harmlessly to earth. The suspended ball, being now free of electricity, was again attracted to the rod, again repelled to the bell, and so on as long as lightning was about.

With the electricity so obtained from the clouds he repeated nearly all the experiments for which before he had employed the frictional machine.

When twitted by his opponents "*à quoi bon*—what is the use of all this?" Franklin would say—"what is the use of a new-born baby? It may become a man." Thus he showed us the bent of his mind, for in his opinion practical utility was or should be the ultimate aim of all science and philosophy. At first there was a great outcry in England against these "impious" proposals in defiance of the ways of beneficent Providence. The battle raged for a time and in the end involved the King, George III. Meeting one day Sir John Pringle, President of the Royal Society, His Majesty wished him to enter the lists against the lightning-rod men with an authoritative proof of the futility of their proposals.

"But, your Majesty, I cannot disprove the laws of nature."

"You cannot? Then I must find a president who can!"

The President resigned (1778), "in consequence of ill-health," ridicule did the rest, and science went victoriously on its way.

An account of these experiments would be incomplete without some reference to the first martyr of electrical science. This was Prof. Richmann of St. Petersburg, who, on repeating Franklin's experiments with a kite, was killed by the discharge in August 1753.

THE HISTORIAN OF ELECTRICITY

Joseph Priestley (see Plate 7), an eminent dissenting divine, chemist and natural philosopher, was born in 1733, at Fieldhead near Leeds, and died in 1804 in Pennsylvania. His works extend to over 70 volumes, many of which are highly polemical, and for one of which, "History of the Corruptions of Christianity," his house in Birmingham, his library and apparatus, were committed to the flames (July 1791) by a riotous mob,

and he himself subsequently (1794) escaped personal danger by fleeing to America. He is best known to science for his pneumatic and chemical researches, culminating in his discoveries of oxygen and other gases, and for his Royal Society paper on the properties of fixed air, which brought him the Copley Medal in 1772. But to us electricians he is especially known as the historian of electricity. His "History and Present State of Electricity," first published in 1769, is still to-day a standard work on its subject. In it are given some of his own contributions, as on "Theories of Electricity"; on "New Experiments in Electricity Made in 1766"; on experiments in which rings consisting of all the prismatic colours were formed on metal surfaces by electric explosions (*Priestley's rings*); and in experiments on the "lateral discharge" of electricity, showing the oscillatory character of these electrical phenomena.

ANIMAL ELECTRICITY.

Before concluding this Section a few words must be said upon the early history of what has been called "animal electricity." The manifestation of this phenomenon in certain fishes led directly to a study of electrification by chemical action, to which the obsolete term "galvanism" was applied; and this, in turn, became of enormous importance, since it drew attention to the properties of electricity in motion, i.e. of the electric current, as distinct from electricity at rest, or static electricity. Historically, then, animal electricity is the link connecting this Section with the next, and it might properly be placed in either. Scientifically the transient effects of electricity in motion had long been observed in discharges and shocks from machines and Leyden jars, but the production of a steady electric current from such apparatus is hardly possible even to-day, and it is quite impossible to believe that the subsequent work of Faraday could have been built upon those foundations. Scientifically, therefore, as well as historically, the study of animal electricity was a necessary step in the evolution of the subject.

Although many fishes and even some of the lower animals are now known to exhibit electric phenomena, the torpedo was the only instance known to the ancients. Aristotle says: "This fish hides itself in the sand or mud, and catches those that swim over it by benumbing them, a fact of which some persons have been eye-witnesses. The fish has also the power of benumbing men." Pliny writes: "From a considerable distance and if only touched with the end of a spear this fish has the property of benumbing the most vigorous arm, and of riveting the feet of the runner, however swift he may be in the race." Plutarch declares that the torpedo affects fishermen through their drag nets, and that if water were poured on one, the person pouring it would be affected, the sensation being communicated through the water to the hand. Claudian and Galen have written much to the same effect, and Oppian is more explicit, for he describes the organs by which the fish exerts its power. It is, he says, attributable to two organs of a radiated texture situated one on each side of the fish.*

* In 1773 the celebrated John Hunter described the anatomical structure of the torpedo and showed the position of the electric organs. In a fish 18 inches long the number of columns composing each organ amounted to 470.

The ancients knew something also of what we should now call "medical electricity." Thus, we read that Dioscorides, the physician of Antony and Cleopatra, used to cure headaches by applying to the head a live torpedo, and that Anthero, a freedman of Tiberius, was cured of the gout in the same way. The patient had to stand on the seashore with a torpedo under his foot until not only the feet but the legs up to the knees became numb.

The *Gymnotus Electricus* was first made known in Europe in 1671 by Richer, one of a party sent out by the French Academy for astronomical observations at Cayenne. The accounts which he brought home of its "shocking" powers were, however, received with much scepticism, and it was not until the middle of the 18th century that the observations of Condamine, Fermin, Bancroft and others, had fully confirmed Richer's statements. The *Gymnotus*, which inhabits the warmer regions of Africa and South America, delivers stronger shocks than the torpedo, the strokes from the larger ones being, according to Bancroft, instantly fatal. Humboldt relates that, treading upon an ordinary specimen, he experienced a more dreadful shock than he ever received from a Leyden jar, and that he felt severe pains in the knees and other parts of his body, which continued for several hours. According to Bryant a discharge sometimes occasions such strong cramp of the muscles of the hand grasping the fish, that they cannot be relaxed. On the river Old Calabar, the electrical properties of the *Gymnotus* are used by the natives to cure their sick children; a small-sized fish is put into a dish containing water and the child is made to play with it; or he may be put into a tub of water with the fish beside him.

Of the remaining electrical fishes, the *Silurus*, introduced by Adanson in 1751, is an inhabitant of the Nile and Senegal; the *Trichiurus* inhabits the Indian Seas; and the *Tetrasdon* is found near the Canary Islands and along the American coast.

Although Redi (1678), Kempfer (1702) and other skilled anatomists had made many observations on the torpedo, the electrical nature of the phenomena exhibited was not known or even suspected up to the middle of the 18th century. The idea first occurred to Prof. Musschenbrock of Leyden in reference to the torpedo, and about the same time to Adanson in regard to the *Silurus*; but it was not until the years 1772-74 that the fact was clearly established by the investigations of Walsh, Sgravesande, Hunter, Ingenhousz and others.

While the examination of the torpedo was going on in Europe, similar investigations were taking place in America with respect to the *Gymnotus*. These were made in Philadelphia and Charleston by Drs. Williamson and Garden, and the same conclusions on the same data were arrived at.

DEVELOPMENTS FROM ANIMAL ELECTRICITY:

GALVANI AND OTHERS.

Though all these investigations led to the strong presumption that this strange animal power was of the same nature as common or frictional electricity, yet they were far from affording that absolute proof which alone satisfies the requirements of modern science; hence

naturalists had been on the watch for additional evidence. In the hundred years preceding the discoveries of Galvani and Volta we find many observations of a character resembling those which in Volta's hands led to the grand discovery of the primary battery. Thus, in 1671 Richer noticed that the *Gymnotus* was able to produce by its shocks a kind of sympathetic quivering in dead fishes lying around it; and in 1678 Swammerdam in some experiments before his patron, the Grand Duke of Tuscany, produced convulsions in the muscle of a frog by pressing the muscle against a brass ring from which the frog was suspended. Du Verney in 1700 made a similar observation, and Caldani described, in 1757, what he called the revival of frogs by electric discharges. Finally, experiments of a similar kind were described in the *Philosophical Transactions* for 1732, in Dr. Alexander Stuart's paper entitled "Experiments to Prove the Existence of a Fluid in the Nerves." In their results all these experiments were the same as those with which the name of Galvani is associated, nor was the mode of operating very different. In Galvani's experiment excitation was produced by contact with a particular nerve, while in Stuart's the convulsions were produced by exciting the spinal marrow.

Sulzer, in his "Nouvelle Theorie des Plaisirs" (Berlin, 1767), described the peculiar taste produced by pieces of silver and lead in contact with each other when applied to the tongue. If the metals be applied in one order the taste will be acidulous, if in the inverse order it will be alkaline. He, however, had no suspicion of the electrical nature of this effect, but thought it "not improbable that by the combination of the metals a solution of either of them may have taken place, and that the dissolved particles may have affected the tongue; or we may conjecture that the combination of the metals occasions a trembling motion in their respective particles, which, exciting the nerves of the tongue, causes the peculiar sensation."

The next person to whom chance afforded an opportunity of forestalling Galvani, but who let it pass with as little profit as Sulzer and his predecessors, was Dominico Cotugna, professor of anatomy at Naples. In a letter dated the 2nd October, 1784, to the Chevalier Vivenzio, he says: "Intending to dissect a mouse, I had hardly cut through that part of the skin covering the epigastric region when the animal's tail vibrated so violently between my fingers that to my astonishment I felt a shock through my left arm as far as the neck with internal tremors, pain in the muscles, and such giddiness in the head that I dropped the mouse in great fright."

Luigi Galvani was born in Bologna on the 9th September, 1737, and died there on the 4th December, 1798. His closing years form a sad contrast with those of his great contemporary Volta, who died in 1827 covered with honours. At the moment when he was immortalizing his name, he suffered cruel blows of fortune. He lost his wife, and shortly afterwards was ordered by the Cisalpine Republic to take an oath of allegiance which was opposed entirely to his political and religious convictions. He refused, and was stripped of his position and titles. Reduced to penury, he retired to his brother's house and fell into a state of lethargy, from which he could be roused neither by medical treatment nor by

the decree of the Government which reinstated him as professor of anatomy in the University of Bologna. He died without again filling the chair which he had made so illustrious.

Galvani's discovery is popularly supposed to have originated in an accidental observation on frogs in 1790, but from his papers in the Bolognese *Transactions* on the muscular movement of frogs, 22nd April, 1773, and on the action of opium on the nerves of frogs, 20th January, 1774, it is clear that his experiments were long anterior to this date. However this may be, Gherardi, his biographer, tells us that on the 6th November, 1780, while preparing in the usual manner a frog in the vicinity of an electrical machine with which some friends were amusing themselves, Galvani observed a strong convulsion of the animal's body. Surprised, and supposing that it might be owing to his having wounded the nerve, he pricked it with the point of his knife, but no convulsion ensued. He again touched the nerve with his knife, directing a spark to be taken at the same moment from the machine, and had the pleasure of seeing the contortions renewed. Upon a third trial there was no result, but noticing that he held the knife by its ivory handle, he now grasped the metal and saw convulsions take place each time that a spark appeared at the machine.*

After a number of similar experiments with the electrical machine Galvani tried the effect of atmospheric electricity, and erected on the roof of his house a lightning rod to which were attached metal rods leading down into his laboratory. These he connected with the nerves of frogs and other small animals, and fastened to their legs wires which reached to the ground. As he anticipated, the animals were convulsed whenever lightning appeared and even when a storm cloud passed over the apparatus. In 1786 he resumed the inquiry with the aid of his nephew, Camillo Galvani, and it was in the course of these experiments that certain facts were observed which led at once to the discovery of galvanism. One day in September, Camillo had prepared some frogs for experiment and had hung them by iron hooks from the top of an iron rail of the balcony outside the laboratory ready for use. Soon he noticed that when by accident a frog was pressed or blown against the rail the legs contracted as they were wont to do when excited by the electricity of the machine or of the atmosphere. Surprised at this effect where there was apparently no exciting cause, he called his uncle, but Galvani dismissed it on the assumption that the movements were connected with some unseen changes in the electrical state of the atmosphere. He soon found that this was not the cause, and, after varying the circumstances in which the frogs were placed, he at length discovered that the movements were due to the simultaneous contact of the muscles with the rail and of the nerves with the iron hook, and that the effect was increased by using two different metals such as iron and silver or iron and copper.

* These experiments are similar to, and are explained by, the phenomenon of "lateral shock" or "return stroke" first observed by Wilson of Leeds in 1746. In Galvani's experiment the frog while it lay on the dry table (so being insulated) had its electricities separated by induction at every turn of the machine, and on the passage of every spark their reunion took place without any visible effect. When, however, the animal was connected with the ground through the knife and body of the professor, one of the separated electricities freely escaped to earth, thus rendering a greater inductive charge possible and raising the "return stroke" to a strength sufficient to convulse the dead limbs. It is but fair to add that Galvani himself suggested this explanation some years later.

Galvani, who was an anatomist first and an electrician afterwards, accounted for these effects by supposing that in the animal economy there exists a source of electricity, that at the junction of the nerves and muscles this electricity is decomposed, the positive fluid going to the nerve and the negative to the muscle, that the nerve and muscle are analogous to the internal and external coatings of a charged Leyden jar, that the metallic connection between the nerve and muscle serves as a conductor, and that on making the connection the same discharge takes place as in the Leyden jar. These researches were not made public until the year 1791, when they were published in the Bolognese *Transactions*.

Galvani's theory fascinated for a time the physiologists. The phenomena of animal life had hitherto been ascribed to an hypothetical agent—the *nervous fluid*—which this new discovery had now consigned to oblivion. Electricity was henceforth to be the great vital force by which the decrees of the will were conveyed from the brain to the obedient members of the body.

Section 3.

DYNAMIC OR CURRENT ELECTRICITY.

At the time of the publication of Galvani's discoveries Alessandro Volta of Como (see Plate 8) was already known for somewhat similar researches. These are given in two letters to Cavallo in London, dated 13th September and 25th October, 1792. They were published in the *Philosophical Transactions* of the next year, and brought their author a Copley Medal in 1794.

VOLTA'S CONTACT THEORY.

Naturally Volta, now professor of physics in Pavia University, had his attention directed to the Bolognese experiments and, although he at first espoused Galvani's opinions, his superior sagacity soon enabled him to detect their want of basis. He first ascertained that the contraction of the frog's legs ensued on simply touching, with the ends of a bi-metallic arc, two points of the same nervous filament. He next found that it was possible to produce with the metallic arc either the sensation of light or that of taste by applying it to the eye or tongue respectively. In short, he showed that the exciting cause might be nothing more nor less than ordinary electricity produced by the *contact* of the two metals, the convulsion of the frog being due, as he thought, to the passage of electricity so developed along the nerves and muscles—to a *current* of electricity in fact.

The first analogy which Volta produced in support of his theory of contact was derived from the well-known experiment of Sulzer described on page 1344. There we saw that the taste produced by placing the tongue between the ends of a metallic arc was acidulous or alkaline according to the position of the arc in regard to the tongue. Now it was found that if the tongue were applied to the conductor of an electrical machine the same effects were observed—i.e. an acid or an alkaline taste, according as the conductor were electrified positively or negatively. Volta contended that the identity of the causes should be inferred from the identity of the effects; that as positive electricity produced an acid

savour and negative an alkaline on the conductor of the machine, so the same effects on the organ of taste produced by the metals ought to be ascribed to the same cause.

In August 1796 Volta arranged an experiment which, by eliminating the physiological element, afforded, as he thought, a direct proof of the correctness of his hypothesis. He took a disc of copper and another of zinc and by means of their insulating handles brought them carefully into contact and then quickly separated them without friction. On presenting them to a delicate electroscope the usual indications of electricity were observed, the zinc being found to be feebly positive, and the copper feebly negative.

FIRST REFERENCE TO CHEMICAL ACTION.

Of the numerous philosophers who took part in these investigations one to whom mention is especially due is Fabroni, who in 1792 communicated his results to the Florentine Academy. In this paper is found the first suggestion of the chemical origin of galvanic phenomena. Fabroni supposed that in the experiments of Galvani and Volta a chemical change occurred at the place of contact of one of the metals with the liquid always found on the surface of animal bodies, and that the convulsions were not, as supposed by Galvani, due to animal electricity, nor, as assumed by Volta, to the discharge caused by the contact of the two metals, but they were due to the decomposition of the animal fluid and the consequent transfer of its oxygen to combination with the zinc or oxidizable element. Galvani's hypothesis was soon rejected by all, but a bitter war raged for some time between the partisans of the contact theory of Volta and the chemical theory of Fabroni. Now it is generally conceded that contact between dissimilar metals and chemical action both contribute to the effect. "Perhaps," says Fleeming Jenkin, "it is strictly accurate to say that difference of potential is produced by contact, and that the current which is thereby set up is maintained by chemical action."* But this is anticipation; for at that period the very idea of a "current" of electricity was new. It was the discharge of an electrified body that was in the minds of the investigators; and Fabroni's conception of the part that the animal fluid might be playing was a very real advance.

INVENTION OF THE PILE.

How early Volta conceived the possibility of his greatest invention we do not know, but there exists an important letter from him to Cavallo written in 1793, six years before the development of the "pile," wherein the writer shows a clear understanding of two ideas which at that time were quite new. One of these was the conception of a continuous current, as contrasted with an intermittent discharge, and the other was the production of such a current by means of a pair of dissimilar metal plates separated by a damp non-conductor. The original is in French, but the following is a rough translation of the most important paragraph:—

"I have in fact discovered a new and very peculiar

* "Electricity and Magnetism," p. 55. This complete statement of the case was, the present author believes, first announced in England by Sir Humphry Davy in 1806.

law; a law not appertaining solely to animal electricity, but to ordinary electricity, since this flow of the electric fluid, a flow which, moreover, is not instantaneous as a discharge would be, but maintained as long as there is a connection between the two plates, takes place whether the latter are applied to living or dead animal matter, or to other non-metallic conductors, provided that these contain enough water, or to damp bodies."

In pursuing his investigations Volta felt the necessity of collecting electricity in greater quantities than could be obtained from a single pair of copper and zinc plates, and he sought for some way by which he could combine and, as it were, superpose two or more causes and so multiply the effect. With this object in view he placed alternately one over the other a number of discs of copper and zinc, but found that the effect was no greater than that of a single pair. On further reflection he thought that with such an arrangement there would proceed, according to his own theory, a negative downward and a positive upward current from the first pair of plates, from the second pair a positive downward and a negative upward, and from the third pair a negative downward and a positive upward, and so on. The downward currents would be alternately positive and negative, and the same would be the case with the upward currents; and, since the surfaces of contact were equal, all the intermediate "currents" would cancel and the effect of the pile would simply be that of the two extreme discs.

He now saw the necessity of adopting some expedient by which all the currents in one direction should be of the same sign, and if this were possible it was easy to see that the resulting currents, negative at the bottom and positive at the top, would be as many times greater as there were surfaces of contact. To effect this, he thought, it was necessary to destroy the contact action at all those surfaces from which descending positive and ascending negative currents would proceed; but while this was being done it was essential that the progress of the descending negative and ascending positive currents should be uninterrupted. The interposition, he thought, of any substance which would have no sensible electric action on the intervening discs would attain one of these ends, but to allow the free passage of the remaining currents in each direction such substance should be a sufficiently good conductor of electricity. Volta selected, as the fittest means of fulfilling these conditions, discs of wet cloth between each pair of plates, which, he said, would give rise to no galvanic action, while their moisture would endow them with sufficient conducting power (see Plate 8). This device succeeded beyond all expectation; for not only was the desired effect multiplied, but the "pile" showed itself capable of maintaining a steady flow or current of electricity for considerable periods. In this respect it was an entirely new departure from the charge and discharge of the old electrostatic apparatus, and it opened up the way for the series of discoveries upon which Faraday was to place the crown.

Although the construction of the pile was evolved as early as the middle of 1796, Volta does not appear to have actually made until some three years later the instrument with which his name is imperishably

associated, and it was not until the 20th March, 1800, that he sent an account of it to Sir Joseph Banks, president of the Royal Society. There he says: "I took some dozens of discs of copper, brass, or better of silver 1 inch in diameter (coins for instance) and an equal number of discs of tin, or much better of zinc. I prepared also a sufficient number of discs of cardboard, leather, or some spongy matter capable of imbibing and retaining water, or, what is much better, brine. I placed on a table a disc of silver and on it a disc of zinc, then one of the moist discs, then another disc of silver, followed by one of zinc and one of cardboard. I continued to form of these several stages a column as high as could sustain itself without falling."

DECOMPOSITION OF WATER.

The invention had been scarcely more than hinted at when the constituents of water were discovered by its means. The first four pages only of Volta's letter were dispatched on the 20th March, and as these were kept back until the receipt of the remainder the letter was not read until the 26th June following. The first portion, however, containing the description of the pile was shown about the middle of April to some scientific men, amongst them Sir Anthony (then Mr.) Carlisle, who was engaged at the time in certain physiological studies. Mr. Nicholson, of *Nicholson's Journal*, constructed a pile of 17 silver (half-crown) pieces alternated with equal discs of copper and cloth soaked in a weak solution of common salt. With this Nicholson and Carlisle began their experiments on the 30th April, 1800.

It happened one day that a drop of water was used to make good the contact of the connecting wires, and Carlisle noticed a disengagement of gas from the water. In order to observe better this result a small glass tube was stopped at one end by a cork and, being then nearly filled with water, it was similarly stopped at the other end. Through both corks pieces of brass wire were passed, the points of which were $1\frac{1}{2}$ inches apart in the water. When these wires were connected with the ends of the pile, bubbles of gas were given off from the point of the negative wire, and the end of the positive wire became tarnished. The gas evolved was hydrogen and the tarnish resulted from oxidation of the positive wire.

Nicholson observed that the same process of decomposition of water was carried on in the body of the pile. The exposed side of each zinc was gradually covered with oxide, so that in two or three days the pile ceased to act. Then it had to be taken to pieces and rebuilt with clean materials.* He made the further important observation that using larger discs yielded no greater result in the decomposition of water, or in the power of the shock. Whence he concluded that the repetition of the series is of more consequence than the enlargement of the surface.

ELECTROLYSIS OF CHEMICAL SALTS.

Cruikshank of Woolwich had, by June 1800, confirmed Nicholson's observations respecting the issue of

* He also noticed an efflorescence round the margin of the discs, due to the gradual precipitation of the salt dissolved in the water.

sparks and the decomposition of water. This last effect he repeated in different ways. By using solutions of acetate of lead, sulphate of copper, muriate of ammonia, and nitrates of magnesia and of silver, he found that in each case the metallic base was deposited at the negative and the acid at the positive pole. In the last example he observes: "the metal shot into fine needles like crystals articulated or jointed to each other as in the *Arbor Dianæ*."

While these investigations were proceeding, Ritter, later so distinguished but then young and unknown, made various experiments at Jena on the effects of the pile, and, apparently without knowing what had been done in England, discovered its property of decomposing water and saline compounds, and of collecting oxygen and the acids at the positive pole, and hydrogen and the bases at the negative. He also found that decomposition could be effected through sulphuric acid, the oxygen being evolved on one side of the acid and the hydrogen on the other side.

EVOLUTION OF THE PRIMARY BATTERY.

The experiments in which the pile was used as the source of power showed the desirability of increasing that power by increasing the number of discs; but here a limit was soon reached. At each increase of height the incumbent weight squeezed out more and more of the liquid from the cardboards, so that the energy of the pile gradually decreased and soon ceased altogether. To prevent this, Ritter adopted a partial remedy. He turned up the edges of the lower discs so as to retain the liquid, and in this way his piles were able to function for 12–14 days; but the apparatus still had to be taken to pieces, the metals cleaned, and the cardboards re-soaked in the solution for every new experiment.

Volta himself—seeing these inconveniences—proposed an arrangement which he called *la couronne des tasses*, consisting of a circle of small cups, each containing a solution of salt. In each cup were placed apart small plates of zinc and silver, the zinc of the first cup being connected by a wire to the silver of the second, the zinc of the second to the silver of the third, and so on. The silver plate of the first cup and the zinc plate of the last formed the poles of the apparatus. Twenty such combinations were able to decompose water, and 30 gave a distinct shock to the moistened hand.

A more convenient form was that known as Cruickshank's battery, which was constructed in England within a few weeks of the publication of Volta's discovery. It consisted of a number of pairs of zinc and copper plates soldered together and cemented into grooves in an oblong trough of hard wood, the spaces between each pair of plates being filled with the exciting liquid. On this plan was constructed the great battery of 600 pairs given to the Polytechnic School of Paris by Napoleon, with which Gay-Lussac and Thenard made their experiments in 1808.*

Dr. Babington's arrangement was another improvement. The plates of copper and zinc 4 inches square were united in pairs by soldering at one point only. The trough in which they were immersed was made of

* A story is told of this battery from which Napoleon received a shock through the tongue, rendering him senseless for a time (see Dr. Paris's *Life of Sir Humphry Davy*).

porcelain and divided into 10 or 12 equal compartments. The plates were hung from a bar of wood, well baked and varnished, and so arranged that each pair should have a partition between them when let down into the trough. By this means the whole set could be lowered into or raised out of the cells, and thus the action of the battery could be suspended at pleasure, and the plates if corroded could be easily replaced. A battery of 2 000 pairs with a surface of 128 000 square inches was made on this plan for the Royal Institution, and with it Davy and Faraday performed many of their brilliant experiments. Children, in 1809, Wollaston, in 1815, Berzelius, in 1818, and others, proposed various modifications of the trough battery, all having for their object increase of power with greater constancy, more cleanliness, and less waste.

INVESTIGATION OF THE PROCESS OF ELECTROLYSIS.

When the chemical powers of the pile became known in England Sir Humphry (then Mr.) Davy (see Plate 9) was beginning those labours in chemical research which later surrounded his name with so much lustre. Owing nothing to fortune, but proceeding on a plan which he had mapped out for himself, he had acquired in his 18th year a sound knowledge of chemistry and the physical sciences. At the age of 19 he was thinking of going to Edinburgh to follow the medical course, but here chance stepped in. As "young Davy who is so clever at chemistry" a friend introduced him to the celebrated Dr. Beddoes of Bristol, who, quick to see the young man's talents, offered him the post of superintendent of his newly-founded Pneumatic Institute for investigating the medical properties of gases. Davy at once accepted the offer, and thus the young philosopher was fairly entered (1798) on his brilliant career, which justified his claim of after years—"What I am I have made myself; I say this not in any spirit of boasting but in all sincerity."

The circumstance attending electrical decomposition which caused great surprise was the production of one element of the compound at one pole and the other element at the opposite pole, without any discoverable transfer of the disengaged elements. If the decomposition was said to take place at the positive end the constituent appearing at the negative end must have travelled through the fluid from the positive to the negative pole, and vice versa. But what appeared still more unaccountable was, that in the experiment of Ritter it seemed that one or other of the elements of the water must have passed through the interposed sulphuric acid. So impossible did such an invisible transfer appear to Ritter that he regarded his experiments as proving that one portion of the water was wholly converted into oxygen and the other portion wholly into hydrogen.

This question was the first to attract the attention of Davy, and it occurred to him to try whether decomposition could be effected in water contained in separate vessels but united by a conducting substance. For this purpose the positive and negative wires were immersed in two separate glasses containing pure water. So long as the glasses remained unconnected, no change was produced, but when Davy put a finger of his right hand into one

glass and of his left hand into the other, decomposition was immediately set up. The same experiment was repeated, making the connection between the glasses by a chain of three persons. If anything passed between the wires in this case it must have gone through the bodies of those persons. The use of the living body being inconvenient where experiments of long continuance were desired, Davy now substituted fresh muscular fibre, the conducting power of which, though inferior to that of the living body, was sufficient. When the glasses were connected by this substance decomposition went on as before but more slowly. To ascertain whether metallic connection between the glasses and the pile was essential he placed lines of muscular fibre between them, and at the same time connected the glasses by a metal wire. He was surprised to find oxygen forming in the glass on the negative side of the pile and hydrogen in the glass on the positive side, the contrary of what occurred when the pile was connected with the glasses by wires. In none of these cases did he observe any disengagement of gas from the muscular fibre or from the living hand while immersed in the water.

After many and varied experiments of this kind Davy began in October 1800 an investigation of the relation which the electrical effects of the pile had to the chemical action of the liquid on the more oxidizable of the metallic elements. He showed that at ordinary temperatures zinc connected with silver suffers no oxidation in water well purged of air and free from acids, and that with such water the pile is incapable of evolving any electricity which can be made sensible either by the shock or by decomposition; but if the water hold oxygen or acid in solution, then the oxidation of the zinc takes place and electricity is sensibly evolved. In fine, he concluded that the power of the pile was in great measure proportional to the chemical affinity of the liquid for the zinc plate.

The inventor of the pile maintained that among the metals which gave the best results were silver and zinc, and that consequently these metals paired in a pile would be more effective, *cæteris paribus*, than any other combination; but as Davy had shown that pure charcoal was a good conductor, he thought that charcoal in combination with a metal would also produce voltaic action. Dr. Wells was the first to prove this fact by showing that such a combination of charcoal and zinc produced sensible convulsions in a frog. Subsequently, Davy constructed a pile or battery of eight glasses with small pieces of well-burnt charcoal and zinc in a solution of red sulphate of iron. This arrangement gave sensible shocks and rapidly decomposed water. Compared with a similar series of silver and zinc its effects were much stronger.

THE DISCOVERY OF THE ELECTRIC ARC.

The date usually assigned to Davy's recognition of the spark from carbon points as a source of lighting is 1809, but for some years before this its possibilities were more than suspected. In a letter of the 22nd September, 1800, Davy himself, while yet Dr. Beddoes's assistant in Bristol, wrote: "The earlier experimenters on animal electricity noticed the power of well-burnt charcoal to

conduct the common galvanic influence. I have found that this substance possesses the same properties as metallic bodies in producing the shock and spark when made a medium of communication between the ends of the galvanic pile of Signor Volta." Then in the *Journal of the Royal Institution*, 1802, he says: "When, instead of metals, pieces of well-burnt charcoal were employed the spark was still larger and of a vivid whiteness."

In all these experiments the voltaic pile was used, but there was no development of the spark into a continuous luminous arc. This was done in Davy's later researches at the Royal Institution, when he used batteries varying from one hundred pairs of plates in 1801 to two thousand pairs in 1809. Thus we read in the *Philosophical Magazine*, January-June, 1810: "In Davy's concluding lecture at the Royal Institution the large voltaic apparatus consisting of 2 000 double plates of 4 inches square was put into action for the first time. The effect of this combination, the largest that has ever been constructed, was, as might be expected, of a very brilliant kind. The spark, the light of which was so intense as to resemble that of the sun, struck through the air and formed an arc of nearly 3 inches in length and of a dazzling splendour. Several bodies which had not been fused before were now melted by this flame, such as iridium, the alloy of iridium and osmium, zircon, and alumine-charcoal was evaporated, and plumbago appeared to fuse *in vacuo*. Charcoal was heated to an intense whiteness in oxymuriatic-acid gas and ultimately volatilized."

In 1813 Davy, accompanied by his wife and young Faraday, made a tour of France, Italy and Switzerland, and met many of the leading scientists of each country. They did not make a long stay in Paris, for, if the truth must be told, Davy failed to make himself popular. Leaving Paris on the 29th December, and travelling slowly, they passed through Lyons, Montpellier, Aix and Nice, thence over the Col de Tende to Turin and Genoa, arriving in Florence early in March 1814. Here in the home of Galileo and his disciples, the atmosphere of which is still permeated by their spirit, they had an enjoyable time, and here Davy made his "grand experiment of burning the diamond" by means of the sun's rays concentrated through the powerful crystal lens of Bregano of Dresden (now preserved in the Tribuna di Galileo, Florence).*

AN APPLICATION OF ELECTROLYSIS.

It will be appropriate here to say a few words about Davy's handling of another problem of great practical utility. About the year 1823 the Commissioners of the Navy called public attention to the rapid decay of the copper sheathing of ships where exposed to the action of sea water. Now, one of the laws of electrical agency which Davy himself had established was that two substances can combine chemically only when they are in opposite electrical states, i.e. one positively and the other negatively electrified. The copper sheathing and the sea water are in such relation that chemical action must take place between them. To prevent this it will only be necessary to change the electrical condition of that one of them (the copper) which we can submit most readily to treatment. After trying various suggestions

* See Plate 9.

he adopted the ludicrously simple plan of placing strips of some other metal—preferably zinc—in close contact with the copper. Now we have a huge battery element or couple in which the water must leave the copper alone and give all its attention to the zinc. The result of actual experiment surpassed his expectations. As if by a wave of a few (zinc) wands, in the manner of a magician, he brings into play the mighty forces of chemical affinity and compels the acids in the sea water to cease attacking the copper, for which their affinity is less, and to concentrate on the zinc strips.*

Unfortunately, it was found in practice that, while this method prevents the wasting of the copper sheathing, seaweeds and marine insects accumulate in such quantities on the bottoms of ships so protected, that they become clogged after a short time and are difficult to navigate. The use of Davy's method has perforce been abandoned—but another Davy will find the remedy.

Sir Humphry Davy died at Geneva on the 30th May, 1829, at the comparatively early age of 51 years, but in 1929 we did *not* celebrate the centenary of his death. Let us think a little of him on this occasion, if for no other reason than that he it was who "discovered" Faraday. "My best discovery," he used to say, "was Michael Faraday." No small words from such a man as Sir Humphry Davy.

SUBSEQUENT DEVELOPMENT OF THE PRIMARY BATTERY.

William Hyde Wollaston (see Plate 9) was almost as remarkable a man as Davy. He was born in 1766, one of a family of, the author believes, 17 children. He studied at Cambridge, and graduated M.D. in 1793. He set up in London as a physician, but want of patronage induced him to give up the profession in disgust, and devote himself to scientific pursuits, with the result that he became one of the most eminent chemists and experimental philosophers of his time. About 1794 he was elected F.R.S., subsequently became secretary, and then president, *locum tenens*, from the death of Sir Joseph Banks in June, 1820, to the election of Sir Humphry Davy in December of the same year. Of many of his varied activities we must content ourselves with a summary, as they are rather outside the limits we have set ourselves in this paper. He discovered rhodium and palladium, and the method of rendering platina malleable—a valuable process from which he is said to have made the sum of £30 000. He was the first to discover in the solar spectrum several of the dark lines, of which some years later Fraunhofer noted some hundreds. He also discovered the ultra-violet rays, invented the goniometer and the camera lucida, and contributed numerous papers to the *Philosophical Transactions* on optics, chemistry and electricity.

His researches on the last-mentioned subject, printed in the *Philosophical Transactions* for 1801, are marked throughout by his accustomed sagacity and penetration. Like Davy, he observed that the energy of the pile seemed to be in proportion to the tendency which one of the metals had to be acted upon by the interposed fluid. "If," he says, "a plate of zinc and a plate of

silver be immersed in dilute sulphuric acid and kept asunder, i.e. not connected by wire, the silver is not affected, but the zinc begins to decompose the water and to evolve hydrogen.* If the plates be now connected by wire, hydrogen collects on the silver plate, and the zinc continues to be attacked and dissolved by the acid." From these and analogous facts he concludes that electricity is produced whenever a metal is dissolved by an acid.

Davy's experiments had shown that in all voltaic combinations only one of the metals is attacked by the liquid, but Wollaston now showed that this condition, although desirable, is not essential. It is sufficient if the chemical action of the liquid on one of the metals be greater than the action upon the other, for then the two metals may be considered to be giving rise to two currents, of which the one proceeding from the metal more attacked is the stronger. The resultant current is the difference between the two. As the voltaic current, then, is produced whenever two metals are placed in metallic contact in a liquid which acts more powerfully upon one than upon the other, it is easy to see that there must be a great choice of pairs.

Wollaston was the first to employ the smallest couple ever made, in which, by the way, he had many imitators in later years. This consisted of a brass thimble containing a few drops of sulphuric acid solution into which dipped a little strip of zinc. A platinum wire which was used to make the connection was fused.

Apparently much of his apparatus consisted of similar simple contrivances. The story is told that one day an eminent savant from abroad called on him and begged to be shown over "the laboratory in which science had been enriched by so many important discoveries." Wollaston took his visitor into a little study and, pointing to an old tea-tray on which were a few watch-glasses, test-papers, a small balance and a blow-pipe, said: "There is all the laboratory that I have."

TWO-FLUID BATTERIES.

All the arrangements of two metals in one fluid, now called single-fluid batteries, had one great defect—their power, variable from the first, gradually declined and sooner or later ceased altogether. This was due to two causes, first, decrease of chemical action owing to the gradual neutralization of the sulphuric acid by its combination with the zinc, and second, polarization of the negative or copper plate, giving rise to secondary currents, i.e. currents in a contrary direction to the principal one, which counteract it wholly or partially. Becquerel, of Brussels, was the first to recognize clearly these defects and their remedy. In 1829 he devised the first double-fluid arrangement which prevented polarization of the copper plate and maintained a supply of acid around the zinc plate, thus removing both causes of weakness at once. It was composed of two small glass vessels, one containing concentrated nitric acid and the other a strong solution of caustic potash. The two vessels were connected by a bent glass tube filled with fine clay moistened with a solution of sea-salt. In the vessel containing the alkali was immersed a plate of gold

* A bit of zinc no larger than a pea is sufficient to protect from corrosion 40–50 square inches of copper.

* Clearly the zinc used by Wollaston was impure. Pure zinc is unaffected so long as it is not joined to the silver by a wire.

and in the other a plate of platinum. On connecting the two through a galvanometer a constant and fairly strong current was indicated. In 1830 Wach constructed double-fluid batteries on this plan, using animal bladder as the medium separating the two liquids.

In England, Prof. Daniell of King's College, London, is commonly supposed to have been the first to make a double-fluid battery; but though not the first, his independent researches and memoir on the subject in the *Philosophical Transactions* for 1836 were the means of bringing the improvement into general notice, making it in the end an instrument of commercial utility.*

Section 4.

ELECTROMAGNETISM AND MAGNETO-ELECTRICITY.

EARLY OBSERVATIONS.

From an early period in the history of electricity, philosophers began to point out resemblances between the phenomena which it exhibits and those of magnetism. In both there existed two forces of opposite kind, capable, when separate, of acting with great energy, and exhibiting no signs of activity when combined; there was the same attraction and repulsion between the two magnetisms as between the two electricities, varying in accordance with the same law of inverse squares; the action of free electricity on a neighbouring body was not unlike that which a magnet has upon iron; and, lastly, the distribution of the forces in the one case seemed to differ little from that of the forces in the other. These analogies were supported by several facts of observation. Thus, it had long been noticed that magnetism was communicated to ferruginous bodies by lightning; the compass needles of ships were known to have their poles weakened, and even reversed, by a similar cause—a fact first recorded by English navigators in 1675; and, in 1750, Prof. Wargentin remarked that delicately suspended magnets were affected by the aurora borealis. With such analogies supported by such remarkable facts the suspicion was but natural that the two sciences were allied in some intimate way, and accordingly we find that about the middle of the 18th century the search for this relation became a favourite pursuit.

Swedenborg was the first to express his views boldly on this subject in his "*Principia Rerum Naturalium*" (Dresden, 1734), in which he argued a close relationship on the ground of both being polar forces. In 1748, Beraud, professor of mathematics in the College of Lyons, published at Bordeaux a thin volume of 38 pages which is probably the first distinct treatise on its subject, and which goes to show that a true connection exists, that, in fact, it is the same force only differently manifested.

In studying the points of analogy between lightning and electricity the great Franklin remarked that the latter, like the former, had the power not merely of

destroying the magnetism of a needle but of reversing its polarity. By discharging four large Leyden jars across an ordinary sewing needle he was able to induce such a degree of magnetism that when floated on water the needle placed itself in the plane of the magnetic meridian. When the discharge was sent through a steel wire perpendicular to the horizon it was found to be permanently magnetized, and on reversing the position of the wire and again sending a discharge through it the polarity was either destroyed or entirely reversed. Franklin found also that the polarity of the loadstone could be destroyed in a similar way.*

Dalibard about the same time imagined that the electric discharge gives a North polarity to that end of a steel bar at which it enters and a South polarity to that at which it leaves. Wilcke, for his part, was equally satisfied that an invariable connection existed between negative electricity and North polarity.

From a review of all these and observations of his own between 1753 and 1758, Beccaria concluded that the polarity of a needle magnetized by electricity was invariably determined by the direction in which the electric discharge passed with respect to it, and he adopted the polarity of ferruginous bodies struck by lightning as a test of the kind of electricity with which the thundercloud was charged. Applying this criterion to the earth itself, Beccaria imagined that terrestrial magnetism was like that of the needles magnetized by Franklin and Dalibard, and was the effect of permanent currents of electricity established and maintained upon its surface by various physical causes; that, as a violent current like that of lightning evokes magnetism in ferruginous substances, so may a gentle and constant circulation of the electric fluid upon the earth impress the same virtue on all such bodies as are susceptible to it. "Of such fluid thus ever present," says Beccaria, "I think that some portion is constantly passing through all bodies situate on the earth, especially those which are ferruginous, and I imagine it must be those currents which impress on fire-irons and other similar things the power which they are known to acquire of directing themselves according to the magnetic meridian when properly balanced."

In the year 1774 the following question was proposed by the Electoral Academy of Bavaria as the subject of a prize essay: "Is there a real and physical analogy between electric and magnetic forces, and if such analogy exist in what manner do these forces act upon the animal body?" The essays were collected and published 10 years later by Prof. Van Swinden, the winner of one of the prizes. Some of the writers, amongst them Van Swinden, maintained that the similarity was but apparent and did not amount to a real physical resemblance, while others, such as Professors Steiglehner and Hubner, contended that "so close an analogy as that exhibited by the two sciences indicated a single agency acting under different circumstances."

THE VOLTAIC PILE AND ELECTROMAGNETISM.

In this unsettled state the subject remained for many years until the discovery of the voltaic pile, which

* Daniell took care to use only well-amalgamated zinc plates in his battery. The first mention of amalgamated zinc in voltaic arrangements occurs in Davy's Bakerian Lecture for 1826, in which he simply remarks that zinc in amalgamation with mercury is positive with respect to pure zinc, without any distinct allusion to the beneficial employment of it in the construction of batteries. Kemp, of Edinburgh, was the first to employ it in the regular construction of batteries as a sure preventive of "local action."

* Many years later Davy proposed to magnetize steel rods by fixing them at right angles to a lightning conductor.

furnished the experimenter with the means of maintaining a continuous current of electricity in large quantity and enabled him to study its effects under the most favourable conditions.

The honour of the discovery of this much-sought-for connection has often been claimed for Romagnosi, an Italian writer who is justly esteemed for his works on history, law and political philosophy. Govi, however, in 1869 showed in the clearest manner the absurdity of this claim. Nevertheless, it was again put forward in our day by Dr. Tommasi of Paris in the number of *Cosmos—Les Mondes* for the 30th June, 1883. Now, we should have thought that after the *exposé* of Govi no electrician would seriously have held these views, and if Dr. Tommasi had read carefully the facts on which he based them he would have seen that they have no relation to electromagnetic action, and are simply effects of ordinary electrical attraction and repulsion brought about by the static charge which always accumulates at the poles of a strong voltaic pile (the form of battery used by Romagnosi), which, as is well known, exhibits this phenomenon in a higher degree than the ordinary cell arrangement.

To the same category belongs the contrivance of Schweigger, described in Gehlen's *Journal für die Chemie und Physik*, 1808, on the strength of which the discovery of electromagnetism has been claimed for the celebrated inventor of the galvanometer. Schweigger's paper simply describes an electroscope for indicating the attraction and repulsion of frictional electricity which he used as a substitute for the torsion electrometer of Coulomb. It consisted of a magnetic needle, armed at each end with a little brass knob and mounted on a pivot as in the ordinary compass. As little value attaches to the observation of Mojon which we find recorded by Aldini,* and which is but a repetition of Franklin's experiment with this difference, that a voltaic battery is used instead of Leyden jars. In a paper read before the Royal Academy, Munich, May 1805, Ritter advanced some curious speculations which are quoted as suggestive of electromagnetism, but are really as wide of the mark as the experiments of Romagnosi, Schweigger and Mojon. They are described in the *Philosophical Magazine* of 1806.

Nor can we give Oersted credit at this period for any more definite comprehension. In a work which he published in German in 1807 on the identity of chemical and electrical forces he says: "When a plate composed of several thin layers is electrified and the layers afterwards separated, each is found to possess an electric polarity, just as each fragment of a magnet possesses a magnetic polarity. There is, however, one fact which would appear to be opposed to the identity of magnetism and electricity. It is, that electrified bodies act upon magnetic bodies as if they were endowed with no force of their own. It would be very interesting to science to explain away this difficulty, but the present state of physics will not enable us to do so. . . . Steel, when heated, loses its magnetism, showing that it becomes a better conductor by elevation of temperature, like electrical bodies. Magnetism, too, like electricity exists in all bodies in nature as Bruckmann and Coulomb have

shown. From this it seems that the magnetic force is as general as the electric, and it remains to be seen whether electricity in its most latent state (as galvanism) will not affect the magnetic needle as such."

OERSTED'S CRUCIAL EXPERIMENT.

In trying experiments to elucidate these hazy notions, Oersted, by a happy impulse or by chance, closed the battery circuit which hitherto had always been left open, and to his delight he saw the needle move from its position of rest. This occurred at a private lecture to advanced students in the winter of 1819-20. With kindling eyes, it is said, he searched the faces around him, and while announcing the result in a few hurried words he pointed to the apparatus with trembling hands and invited the students to make the experiment for themselves. Thus, at last, was discovered the long-sought secret of the connection between electricity and magnetism—to which Faraday was to put the keystone 11 years later.

After further experiments, in the spring of 1820 Oersted wrote an account of his discovery in Latin. It was published on the 21st July of that year, and copies were sent to prominent persons, societies and science reviews, at home and abroad. In this he says: "The first experiments respecting the subject which I mean to explain in this treatise were made by me last winter while lecturing on electricity, magnetism and galvanism, in the University of Copenhagen. It seemed to be demonstrated by these experiments that the magnetic needle was moved from its position of rest by the galvanic apparatus only when, and as long as, the circle was closed, and not when it was open, which last method was tried in vain for some years by very celebrated philosophers. As, however, my experiments were made with a feeble apparatus they were not sufficiently conclusive, and so, considering the importance of the matter, I associated myself with my friend Esmarck, Councillor of Justice, to repeat and extend them by means of a powerful galvanic battery consisting of 20 pairs of copper and zinc plates, each 12 inches square. The terminal ends of this battery were connected by a wire which we shall call the conductor. What takes place in this conductor and in the space surrounding it we shall call the conflict of electricity. Let the straight part of the conductor be placed horizontally above the magnetic needle and parallel to it, the needle will move its end next the negative pole of the battery towards the west. If the distance of the conductor from the needle does not exceed $\frac{3}{4}$ inch the declination is about 45° , and if the distance is increased the angle diminishes proportionately. The declination also increases with the strength of the battery. The conductor may change its place to the east or the west of the needle (remaining always parallel to it) without causing change other than the amount of the deflection. If the conductor be placed in a horizontal plane under the needle the effect is the same as when above it, except that the needle moves in the opposite direction."

This most important discovery may be succinctly stated thus —Supposing the electric current to pass from north to south through a wire placed horizontally in the magnetic meridian, then a compass needle suspended

* "Essai Théorique et Expérimental sur le Galvanisme," Paris, 1804.

above it will have its north end turned towards the west; if below the wire to the east; if on the east side, the north end will be raised; if on the west side, it will be depressed.

FOUNDATIONS OF ELECTRO-DYNAMICS.

The effect of Oersted's publication was widespread. The enthusiasm which had been lighted up by the discoveries of Galvani and Volta 20 years before had cooled down, and it seemed to be the general opinion in England as late as 1818 that there was nothing more to be discovered in this way.*

This enthusiasm was now reawakened and the resources of every laboratory were brought to bear on the pursuit of the consequences of this new relation between sciences so long suspected of closer ties. The inquiry was taken up more particularly by Ampère and Arago in France; by Davy, Faraday, Cumming and Sturgeon in England; by Seebeck, Schweigger, De la Rive, Henry and other physicists, in all parts of Europe and America.

Among these Faraday is *facile princeps*, but Ampère holds a distinguished place in a great galaxy of scientists. No sooner was Oersted's discovery made known than Ampère commenced those beautiful experiments which have surrounded his name with so much lustre, and have brought electro-dynamics within the pale of mathematical physics. On the 18th September, 1820, within two months of Oersted's publication, he communicated his first memoir on electromagnetism to the Academy of Sciences, Paris.

In this paper he explained the law determining the position of the magnetic needle in relation to the electric current. He also noticed that the pile itself affected the needle in the same way as did the connecting wire, and showed that this effect was consistent with the theory that the electric current completes its circuit back to the pole from which it started. In the same memoir were described several instruments which he intended to construct, especially spiral or helical wires through which to send electric currents and which it was expected would thereby acquire the properties of magnets and retain these properties so long as the current passed through them. Ampère also explained his theory of magnets, ascribing their attractive and directive powers to currents of electricity circulating round their molecules in planes at right angles to the line joining their poles, the nature of the poles on one side or the other of these planes depending on the direction of the currents.

FIRST SUGGESTION OF A TELEGRAPH.

Soon after Oersted's discovery of the power of the current to deflect the magnetic needle, Laplace the distinguished French philosopher suggested its employment for telegraphic purposes; and on the 2nd October of the same year, 1820, Ampère sketched out the idea in a paper read before the Academy of Sciences, Paris. He says: "According to the success of the experiment to which Laplace drew my attention one could, by means

of as many pairs of conducting wires and magnetic needles as there are letters, establish by the aid of a pile placed at a distance a sort of telegraph which would be capable of indicating all the details that one would wish to transmit through any number of obstacles to a distant observer. By connecting with the pile a key-board, each key corresponding to a connecting wire would by its depression indicate a letter, and thus a correspondence could be established with great facility, and would only occupy the time necessary for touching a letter at one end and noting it at the other." This suggestion was not meant as a practical one and was thrown out simply *par parenthèse* in the course of his paper. It will be seen that he makes no mention of surrounding the needles with coils of wire, as is so frequently stated by writers on the telegraph, and without which the contrivance would be useless at the shortest distances. Indeed he could not then have even heard of the galvanometer, or multiplier principle, for although Schweigger's paper on the subject was read at Halle on the 16th September, 1820, it was not published until the November following.*

DEVELOPMENTS FROM OERSTED'S DISCOVERY.

While Ampère was engaged in these investigations his fellow-countryman Arago directed his inquiries to the state of the wire through which the current was transmitted, with a view to determining whether every part of it was endowed with the same magnetic properties. With this intent he placed iron filings around the wire and found that they adhered to it so long as the current flowed (as in the case of an ordinary bar magnet), and fell away immediately the connection with the battery was broken. This proved not only that the wire had the power (already observed) of acting on magnetic bodies, but that it was itself capable of developing temporary magnetism in soft iron. The same attraction took place with wires of brass, silver, platina, etc.; and that it was not a purely electrical effect was proved by the fact that the conducting wire had no power over filings of copper or brass, or sawdust. He also found that on placing small steel needles across the wire carrying a current from a voltaic pile, or a discharge from a Leyden jar, they were attracted and, on removal, found to be permanently magnetized. Acting upon Ampère's theory of magnetism, he placed in a glass tube an ordinary sewing needle and wound round the tube a copper wire. On sending a current through the wire the needle was magnetized, its polarity depending on the direction of the current. If the helix were right-handed the south pole of the needle was found at the end at which the current entered, if left-handed the same end was a north pole. In the same way he was able to impart temporary magnetism to soft-iron rods.†

EVOLUTION OF THE GALVANOMETER.

Another very important discovery which followed fast on the heels of Oersted was that of Schweigger of Halle,

* Of Ampère's astatic needle galvanometer, we shall speak presently (see page 1353).

* See, for example, Bostock's "History and present state of Galvanism," published in London in 1818, page 102. Napoleon did not share these views. In the First Consul's letter to the Minister, Chaptal, founding two prizes to encourage new researches in galvanism, he said: "Galvanism in my opinion will lead to great discoveries."

† Independently of Arago's experiments in Paris, Davy in London succeeded about the same time in magnetizing needles by the voltaic current as well as by ordinary frictional electricity, and also showed the effect of the conducting wire on iron filings. See his letter to Wollaston of the 12th November, 1820, in the *Philosophical Transactions* for 1821.

announced in 1820. Observing that the deflection produced by the outward current of a battery flowing over the needle was the same as that of the returning current under the needle, he made the wire proceed from his battery *above* the needle and return *beneath*, and obtained, as he expected, twice the effect. By giving the wire another turn, the effect was again nearly doubled, and a third turn again increased the original deviation, and so on.

On this principle were made instruments for indicating and measuring currents of electricity called "electromagnetic multipliers," or more commonly "galvanometers," the former being the name originally given to it by its inventor, Schweigger. His first contrivance was a humble affair, consisting of a small compass-box round which were coiled several turns of copper wire in a direction parallel to the meridian line of the card. Yet this was the prototype of the beautiful instruments of Du Bois-Reymond and Sir William Thomson (afterwards Lord Kelvin), in the former of which as many as 30 000 convolutions are sometimes employed. There was, however, still wanting another improvement to bring the galvanometer to a state of perfection, and this was soon supplied.

In deflecting a magnetic needle the current has to overcome the force of inertia plus the force of terrestrial magnetism, which tries to bring back the needle to its position of rest. Now, if that force could be neutralized, the deflection would be greater; in other words, a galvanometer in which the needle is freed from the action of the earth's magnetism would be more sensitive than the same instrument when its needle was not so freed. This idea led Ampère to the invention of the double or astatic needles which he describes in his memoir of 1821: "When a magnetic needle is withdrawn from the directive action of the earth it sets itself under the influence of the voltaic current in a direction which makes a right angle with the conducting wire and has its South pole to the left of it. If M. Oersted obtained deviations of less than a right angle it was solely because the needle was not withdrawn from the influence of the earth's magnetism, and consequently took up an intermediate position—the resultant of the two forces acting upon it. There are several ways of withdrawing a magnetic needle from the earth's action. A simple one consists in attaching to a stout brass wire (which has its upper part curved and fitted with a steel suspensory point) two needles of equal strength in such a manner that their poles are in opposite directions, so that the earth's directive force upon one is neutralized by the action in the opposite direction which it exercises on the other. The needles are so arranged that the lower one is just below the coil of wire and the upper one close above it. On sending a current through the convolutions the needles turn and take up a direction at right angles to the meridian line."

In Prof. Cumming's paper read before the Cambridge Philosophical Society on the 2nd April, 1821, he describes a near approach to the astatic principle. In order to neutralize the earth's magnetism he placed a small magnetized needle under the needle of the galvanometer. Sometimes, especially in Italy, the credit of Ampère's discovery is claimed for Leopoldo Nobili, a distinguished

Italian physicist (of whom we shall have more to say later on). He certainly did not invent the instrument, but it is equally certain that he so improved upon Ampère's as to make it one of extreme delicacy.

MAGNETISM BY ROTATION

Arago, in 1824, made another discovery of the greatest importance in electromagnetic engineering. He suspended a magnetized needle in a circular copper cage the bottom and perimeter of which were very near the needle. On swinging the latter he noticed that its oscillations diminished in amplitude and soon ceased, as if the medium had become more and more resistant. By making the needle oscillate at different distances above discs of different materials Arago found that distance greatly diminished the effect, and that metals had a more restraining or damping effect than wood, glass and similar substances.

Arago now tried whether a disc which possessed this remarkable property would, if rotated, affect the needle. The experiment resulted in the discovery of a new class of phenomena, to which he gave the name of magnetism by rotation. If we fix to a rotatory apparatus, such as a table made for experiments on centrifugal force, a copper disc, about 12 inches diameter and $\frac{1}{10}$ inch thick, and just above it suspend by silk fibre a magnetic needle so that its point of suspension is exactly over the centre of the disc (care being taken to interpose a screen of glass or paper so that the agitation of the air caused by the rotating disc does not affect the needle), and if we put the disc in motion, the needle is seen to deviate in the direction of the rotation and to make with the magnetic meridian a greater or less angle according to the speed of rotation. If this be very rapid the needle is deflected more and more until finally it rotates with the disc. The effect diminishes rapidly with the distance of the needle from the disc, and is further lessened by cutting radial slits in the latter, a fact of the highest importance in the construction of electromagnetic machinery.

Whilst Arago was analysing the force that he had discovered, Babbage and Herschel, Barlow, Harris and others, undertook an investigation of the causes that might vary its intensity. Messrs. Babbage and Herschel found that discs of copper and other substances when freely suspended over a rotating horseshoe magnet turned in the same direction as the magnet, with a movement at first slow but gradually increasing. The interposition of plates of glass and of non-magnetic bodies in no way affected the results, but it was not the same with interposed plates of iron. The action was then greatly reduced and even entirely suspended. These two experimenters confirmed Arago's observation on the influence of continuity—partial or total—in the discs subjected to trial. Thus, a light disc of copper suspended at a given distance above a rotating magnet made 6 rotations in 55 minutes. When cut radially in eight places it took 121 minutes to make the same number of rotations, but, on the parts cut out being soldered in place again, the original effect was almost attained, the disc making its 6 rotations in 57 minutes. The same results were obtained with other metals.

Sir W. Snow Harris, who made a number of experi-

ments on this subject, not only found great differences between bodies with regard to their power of drawing the needle after them when rotating, but also differences between those other bodies which have the property of intercepting this action. He observed that iron and magnetic substances are not the only ones which are able to arrest magnetization by rotation. Plates of copper, silver and zinc, will do the same if sufficiently thick—from 3 to 5 inches. From a study of all these results, Christie deduced the law that the force by which different bodies draw after them the magnetic needle in their rotatory movement is proportional to their conducting power for electricity. But a full explanation of these phenomena could not be given until Faraday's discoveries in 1831, when it was proved that they were all the result of electric currents induced in the disc by its rotation in the field of the magnet. In the case of those discs in which slits or rays were cut, the free circulation of these currents was prevented and consequently there was no effect on the needle.

INVENTION OF THE ELECTROMAGNET (STURGEON).

In November 1825 a great advance was made on Arago's experiment (of magnetizing soft iron) in the invention of the electromagnet—an instrument which, in one form or another, is at the basis of all our electrical industries. We owe this contrivance to William Sturgeon (see Plate 3), a well-known electrician of Woolwich, who had worked in his earlier days at the cobbler's last, as Franklin had done at the printing-stick, and Faraday at book-binding. Plate 10 shows the earliest form of the instrument—a piece of stout iron wire bent into the form of a horse-shoe, coated with an insulating varnish, and bound round with bare copper wire, the turns (of which there were 16) being, of course, separated from each other. This, the first electromagnet, when excited by a single voltaic pair of large (130 square inches) surface, was capable of holding a weight of 9 pounds, a wonderful performance in those days.

With the exception of the electromagnet Sturgeon cannot be said to have contributed any capital discovery or generalization to the science, but he was most helpful in elucidating and supplementing the work of others. His friend and biographer, Dr. Joule, writing in the *Memoirs of the Literary and Philosophical Society of Manchester*, 1857, says: "In 1824 Sturgeon began to give the fruits of his investigations in the leading scientific periodicals of the day. In that year no fewer than four papers of great merit appeared on the subjects of Electro- and Thermo-electricity in the pages of the London *Philosophical Magazine*; and in 1825 he published in the *Transactions* of the Society of Arts the description of a complete set of novel electromagnetic apparatus. The great merit of this consisted in the improved adaptation of the magnets, batteries, etc., to one another by means of which he was able to perform with a battery of the size of a pint pot, experiments which had before required the use of a cumbrous and costly battery. The Society of Arts testified their sense of the importance of this contribution by awarding its author their large silver medal and a purse of 30 guineas. About this time Sturgeon made his great discovery of the soft-iron

electromagnet, and having observed the high degree of polarity acquired by a bar of iron on making the current circulate around it, as well as the suddenness with which that polarity could be reversed by means of his commutator, he proceeded to make electromagnets bent in the form of a horseshoe, so that the poles by being close together could concentrate their action on any given object.

Passing over several valuable communications to the *Philosophical Magazine*, we find him in 1830 publishing a pamphlet on experimental researches in electromagnetism, galvanism, etc., comprising an extensive series of original experiments. In this work he pointed out the superior effects derived from the use of amalgamated plates of rolled zinc instead of the unprepared cast zinc then in general use. He prepared his plates by dipping them first in a dilute solution of acid to cleanse their surfaces, afterwards plunging them into mercury (i.e. amalgamating them: see footnote on page 1350). He showed that plates prepared in this way do not effervesce in dilute sulphuric acid (as unprepared plates do) and, in consequence, require less frequent renewal, while the current produced is greater and more constant.

"In our chronological arrangement of Sturgeon's discoveries we may next note a valuable paper on the Thermo-magnetism of homogeneous bodies, a work the merit of which can only be appreciated by those who are acquainted with the extreme minuteness of the currents of which it was the object to discover the existence and direction. By a happy combination of industry and sagacity our author succeeded in proving that electric currents can be developed in any mass of pure metal by a mere disturbance of temperature at some particular point, and that the direction of those currents is determined by the position of the point of greatest heat and the crystalline structure of the metal—a fact of the highest importance, which, along with others developed by him about the same time, paved the way to Dr. Faraday's celebrated discovery of magnetic electricity."*

Here we must stop, as Sturgeon's further work, in all over 50 separate papers, would take us beyond our limit (the year 1832); but we may conclude with a reference to the marble tablet erected to his memory in the parish church of Kirkby Lonsdale. The inscription is nothing more nor less than an epitome or catalogue of his discoveries—surely a very remarkable monument for a country parish church (see Plate 10).

DEVELOPMENT OF THE ELECTROMAGNET (JOSEPH HENRY).

Further steps in the perfection of the electromagnet were made by Prof. Joseph Henry (see Plate 11) in America between the years 1828 and 1831; and it will be interesting to retrace them here, if only to see how little learned professors understood 100 years ago the conditions underlying the relationship between voltaic and magnetic force, and consequently how much groping in the dark and stumbling to conclusions there was, whereas now Ohm's celebrated law makes everything so clear. Henry was led to his first improvements by a

* Seebeck is credited with the discovery of thermo-electricity in 1815.

study of Schweigger's galvanometer, which resulted in the idea that a nearer approximation to the requirements of Ampère's theory could be obtained by insulating the conducting wire itself, instead of the rod to be magnetized, and by covering the whole surface of the rod with a number of coils in close contact.

In June 1828 Henry exhibited at the Albany Academy, Albany, N.Y., where he was then a professor, an electromagnet constructed on this principle. It consisted of a piece of soft iron in horseshoe form, and closely wound with silk-covered copper wire, $\frac{3}{8}$ inch in diameter. In this way he was able to employ a larger number of convolutions, while each turn was more nearly at right angles to the magnetic axis of the bar. The lifting power of this magnet was, conformably to his anticipations, much greater, *ceteris paribus*, than that of Sturgeon. In March, 1829, he showed at the same place a larger magnet, actuated by two small battery plates suspended in a tumbler of dilute acid. With this arrangement he obtained more powerful effects than with a bar of the same size wound according to Sturgeon's method and excited by a battery of 28 pairs of copper and zinc, each plate 8 inches square.

"In the arrangement," says Henry, "of Arago and Sturgeon the several turns of wire were not precisely at right angles to the axis of the rod, as they should be to produce the effect required by the theory, but were slightly oblique, and so each tended to develop a separate magnetism. But in winding the wire over itself the obliquity of the several turns compensated each other, and the effect was at the required right angle. The arrangement, then, introduced by myself was superior to those of Arago and Sturgeon, first, in the greater multiplicity of turns of wire, and second, in the better application of these turns to the development of magnetism in the bar.

"The maximum effect, however, of this arrangement and a single battery pair was not yet obtained. After a certain length of wire had been coiled upon the iron the power diminished with a further increase of the number of turns. This was due to the increased resistance which the longer wire offered to the conduction of electricity. Two ways of improvement suggested themselves. The first consisted not in increasing the length of the coil, but in using a number of separate coils on the same piece of iron. In this way the resistance to conduction would be diminished and a greater quantity of electricity made to circulate round the iron. The second method consisted in increasing the number of battery elements; or in other words the propulsive force of the current, which enabled it to pass through an increased number of turns of wire, and thus develop the maximum of magnetic power in the iron." Employing a horseshoe formed from a cylindrical bar of iron, $\frac{1}{2}$ inch in diameter and 10 inches long and wound with 30 feet of fine copper wire, he found that with a current obtained from only $2\frac{1}{2}$ square inches of zinc the magnet could hold 14 pounds. Winding upon its arms a second wire of the same length (30 feet) the ends of which were similarly joined to the same galvanic pair, the magnet lifted 28 pounds.*

* It must not be forgotten that at this time the strongest electromagnet in Europe was that of Sturgeon. It could sustain 9 pounds and was considered to be a prodigy.

SERIES AND PARALLEL MAGNETIZING COILS.

In the following year, 1830, Henry achieved still better results, assisted by his friend, Dr. Philip Ten-Eyck: "A bar of soft iron 2 inches square and 20 inches long was bent into the form of a horse-shoe. A piece of iron from the same bar and weighing 7 pounds was filed perfectly flat on one surface to act as armature or lifter. The flat ends of the horse-shoe were also truly ground to the surface of the armature. Around this horse-shoe 540 feet of copper bell-wire were wound in nine coils of 60 feet each. These coils were not continued round the whole length of the bar, but each coil, according to the principle above mentioned, occupied about 2 inches and was wound several times backward and forward over itself. The several ends of the wires were left projecting and all were numbered so that the ends of each coil might be readily distinguished. In this way we formed a magnet on a large scale, with which several combinations of wire could be made by merely uniting the projecting ends. Thus, if the second coil be connected end on to the first and so on through the series the whole will form a continuous coil of one long wire, and by different connections they may be formed into two coils of half the length, or into three coils of one-third the length, and so on. The figure [Plate 11] is an exact reproduction of this instrument, which is at present preserved in Princeton College, New Jersey. Two of the wires, one from each leg being soldered together so as to form a circuit of 120 feet, gave a lifting power of 60 pounds. The same two wires connected so as to form a double circuit of 60 feet gave a lifting power of 200 pounds, and four coils connected in the same way supported as much as 500 pounds. Six coils united in three pairs gave a lifting power of only 290 pounds, but the same wires when arranged as six parallel circuits could support 570 pounds or nearly double. When all the nine coils were joined up in parallel circuits a lifting power of 650 pounds was obtained."*

In all these experiments a small voltaic pair was used, consisting of two concentric copper cylinders with a zinc one between, the active surfaces of which (both sides) amounted to only two-fifths of a square foot. The exciting liquid consisted of half a pint of dilute sulphuric acid.

The only European physicist who up to this time (1830) had obtained any results even approximating to these, was Gerard Moll, professor of natural philosophy in the University of Utrecht, who, seeing in London in 1828 Sturgeon's electromagnet, determined to try the effect of a larger galvanic apparatus. Having formed a horseshoe $12\frac{1}{2}$ inches high and $2\frac{1}{2}$ inches thick, he surrounded it with 26 feet of insulated copper wire 1 inch thick in a close coil of 44 turns. The total weight was 26 pounds. With a current from a pair of 11 square feet of active (zinc) surface, the magnet sustained 154 pounds—a result which was considered astonishing in Europe; yet Henry's magnet, less in size and weight, supported five times this load with one-eleventh of Moll's battery power.

* Henry was called to the Chair of Natural Philosophy in Princeton College in 1832, and there made two much larger magnets. One weighing 59½ pounds (now in Yale College) could sustain 2 064 pounds. The other, made in 1833, weighed 100 pounds and could hold 3 500 pounds.

CONNECTION BETWEEN QUANTITY AND INTENSITY OF
THE BATTERY AND SERIES-PARALLEL CONNECTION
OF THE COILS.

After finding that the maximum attractive power was obtained by his artifice of multiple coils, Henry proceeded to experiment with electromagnets formed of one long wire, and was soon rewarded by a new discovery, namely, that though multiple coils yielded the greatest attractive power close to the battery, one long, continuous coil permitted a weaker attraction to be exercised at a great distance. Using his earlier and smaller magnet of 1829, he tried the effects of different battery powers, of different lengths of external wire, and of different lengths of coil. Excited with a single copper and zinc pair of 56 square inches active surface, the magnet sustained $4\frac{1}{2}$ pounds. With 500 feet of copper wire, 0.045 inch diameter, interposed between the battery and magnet the weight supported was 2 ounces, with 1 000 feet of interposed wire the lifting power was only $\frac{1}{2}$ ounce. Using now a trough battery of 25 pairs, the magnet lifted 7 ounces, and with the 1 000 feet of wire interposed it sustained 8 ounces. "From these experiments," says Henry, "it appears that the current from a trough of 25 pairs is able to produce greater magnetic effect on soft iron after traversing more than one-fifth of a mile of intervening wire than when it passes through the coil alone surrounding the bar. It is possible that the different states of the trough with respect to dryness may have exerted some influence on this remarkable result, but that the effect of a current from a trough, if not increased, is but slightly diminished in passing through a long external wire is certain. . . . From these experiments it is evident that in forming the coil we may use one very long wire or several short ones as circumstances may require. In the first case our galvanic combination must consist of a number of plates so as to give projectile force, in the second case it must be formed of a single pair."

Henry was thus the first to work out practically the different functions of two different kinds of electromagnet, the one of short coils which he called the *quantity magnet*, and the other of one long coil the *intensity magnet*. The former and more powerful, although little affected by a battery of many plates (the intensity battery), was fully charged by a single pair (the quantity battery); while the latter and feebler, but very slightly affected by a single pair, was not only excited by a battery of numerous elements, but could receive this excitation from a distant source. In fact, Henry had established the important principle at which Ohm had a short time before (1827) arrived from theoretical considerations, and which is now universally employed under the name of Ohm's law. A corollary of this is, that, by combining an intensity battery with an intensity magnet, a very long external wire can be inserted in the circuit without sensible diminution of the effect.

Thus the intensity battery and the intensity magnet were linked together for the first time, and the old difficulty of the magnetic effect diminishing rapidly as the length of wire increased was solved. "The fact," says Henry, "that the magnetic action of a current

from a trough battery is not sensibly diminished by passing through a long external wire is directly applicable to Dr. Barlow's project of an electromagnetic telegraph, and it is also of material consequence in the construction of the galvanic coil." The question has been asked, why, having discovered all the essentials of an electric telegraph, Henry did not himself propose one. He answered as Faraday did in like case a few years later: "My life has been principally devoted to science, and my investigations in different branches of physics have given me some reputation in the line of original discovery. I have sought no patent for inventions and solicited no remuneration for my labours, but have freely given their results to the world, expecting only in return to enjoy the consciousness of having added to the sum of human knowledge, and to receive the credit to which they may justly entitle me."

EXPERIMENTS ON SELF AND MUTUAL INDUCTION.

In another place he says: "I had no idea at that time (1830) of abandoning my researches for the practical introduction of the telegraph. Indeed, my experiments on the transmission of power to a distance were superseded by the investigation of the remarkable phenomena which I had discovered in the course of those experiments, namely, the induction of a long wire on itself, of which I made mention in a paper in Silliman's *Journal of Science* for 1832." Here Henry refers to experiments which led him to a most important line of research on electric induction and magneto induction, in which he and Faraday and doubtless others were engaged at about the same time, but quite independently of each other. The fact is, this question was very much in the air at this time. Ever since Oersted discovered the property of electricity to deflect a magnetic needle, and Arago its corollary—the magnetizing power of the current—physicists everywhere sought for its converse, the production of electricity by means of a magnet. Immediately after settling at Princeton, Henry resumed the inquiry with coils of insulated copper ribbon, and discovered that the first induced current could produce a second, this in its turn a third and so on. Also that an induced current of intensity could produce one of quantity, and vice versa, and that currents can be induced at a distance. Thus, from the primary current in one room he induced currents in a coil in another room "with no connection, merely by the disturbance of the electrical *plenum*," to use his own words. He obtained the same result from two parallel wires (the inducing and induced circuits) stretched across the college grounds and several hundred feet apart.

He then made the capital discovery, for which every one was seeking, the production of electricity from the magnet, but in this Faraday was just before him. On this point Prof. Fleming speaks with authority. Writing in 1892 he says: "Henry's claim to be an independent discoverer of the fundamental effect of electromagnetic induction is not now disputed. In the July number of Silliman's *Journal of Science* for 1832, Joseph Henry, then a young teacher in the Albany Academy, gave an account of the manner in which he had independently, and before receiving an account of Faraday's work

(performed in the previous autumn), elicited from his own great electromagnet an induced current by wrapping around the soft-iron armature certain coils of insulated wire. Upon making and breaking the circuit of his electromagnet, a current of electricity was induced in the coils surrounding the armature" (see Plate 11).

Section 5.

[NOTE.—Mr. Fahie's original MS. contained a further Section, which, by arrangement with the author, has been combined with the Faraday Lecture by Prof. W. Cramp (see below).]

SEVENTH FARADAY LECTURE.

"THE BIRTH OF ELECTRICAL ENGINEERING." *

By Professor W. CRAMP, D.Sc., Member.

[Lecture delivered before THE INSTITUTION 26th February, before the SOUTH MIDLAND CENTRE 28th January, before the NORTH-EASTERN CENTRE 6th February, before the NORTH-WESTERN CENTRE 10th February, before the MERSEY AND NORTH WALES (LIVERPOOL) CENTRE 16th February, before the WESTERN CENTRE 23rd February, before the IRISH CENTRE 24th March, and before the SCOTTISH CENTRE 8th May, 1931; also at the ANNUAL CONVERSAZIONE 22nd September, 1931.]

The Faraday Lecture was established by the Institution as a perpetual memorial to the founder of our profession. It is intended to arouse interest in electrical matters among those to whom such things are a mystery, and for that reason my predecessors have often dealt in a simple manner with some common applications of electrical power. This year such a course would be inappropriate. The year indeed fixes the subject; and there are two possible methods of dealing with it. I might try to deliver an oration upon Faraday and his work after the French model, or I might try to bring home to you in the simplest and most vivid manner—i.e. by direct experiment—the knowledge of electromagnetism as it was in the month of June 1831 and as it was in December of the same year. I have chosen the second plan, not only because I count myself unfitted for the first, but also because I know that the other is the one that Faraday himself would have selected. My task is rendered all the easier by the fact that Faraday (unlike Ampère) was no mathematician. His methods were essentially those which appeal to the child-like mind; he made use of the convincing evidence of simple experiments, explained in terms of a physical picture. Clerk Maxwell puts the matter concisely when he writes:—"The method which Faraday employed in his researches consisted in a constant appeal to experiment as a means of testing the truth of his ideas, and a constant cultivation of ideas under the direct influence of experiment. In his published researches we find these ideas expressed in a language which is all the better fitted for a nascent science, because it is somewhat alien from the style of physicists who have been accustomed to established mathematical forms of thought." What style could be more appropriate to a Faraday lecture?

Yet the simplicity and directness of Faraday's method are in themselves a source of difficulty to me. For my audience consists of two very different types. There are those who have never read the "Experimental Researches," nor seen apparatus like that which I have prepared. For them, the novelty of experiment and deduction will bring its own interest, however faulty the presentation. But there are also those who have seen such experiments dozens of times, have very likely taught by means of similar apparatus. How can I expect to interest them? My hope is that they may be aroused by a psychological and historical presentation of the subject—that, in fact, I may be able to show the sequence of the ideas as they grew in the mind of the "Father of Electrical Engineering." In order that I might do this the more effectively, I have studied (by the kind permission of Sir William Bragg) the manuscripts at the Royal Institution: I have actually handled those precious records, so fresh from the pen of Faraday, and bound with his own hands. There I found ample evidence that the order of the "Experimental Researches" is not the order of the laboratory notes. The former are indeed derived from the latter, and they appeal as a logical and orderly whole. But the laboratory note-books show how the mind of Faraday went from step to step: we are allowed to "look inside his head," so to speak; and I hope, by putting his experiments in the order of the note-books and by quoting his own comments upon them, that I may provide an interest even for the more sophisticated among my listeners.

Before turning to the events of 1831, let us try to form some idea of the origin of the problem which Faraday solved and of his earlier work on the same subject. The story of the puzzle then confronting all physicists has been traced in Section 4 of Mr. Fahie's retrospect.†

* The Lecture embodies material which was contained in Section 5 of Mr. Fahie's paper (see Note at top of this page)

† Page 1350.